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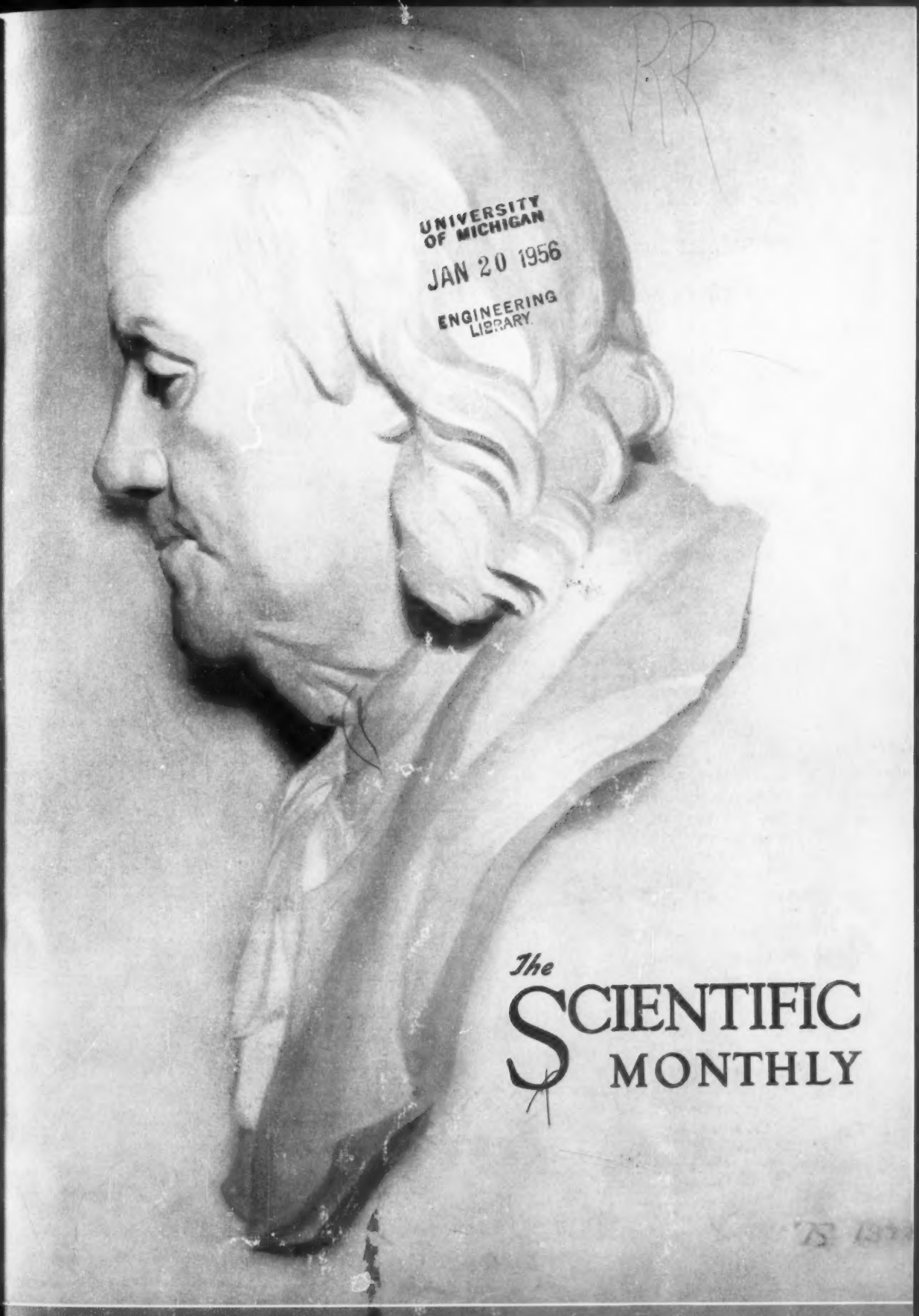

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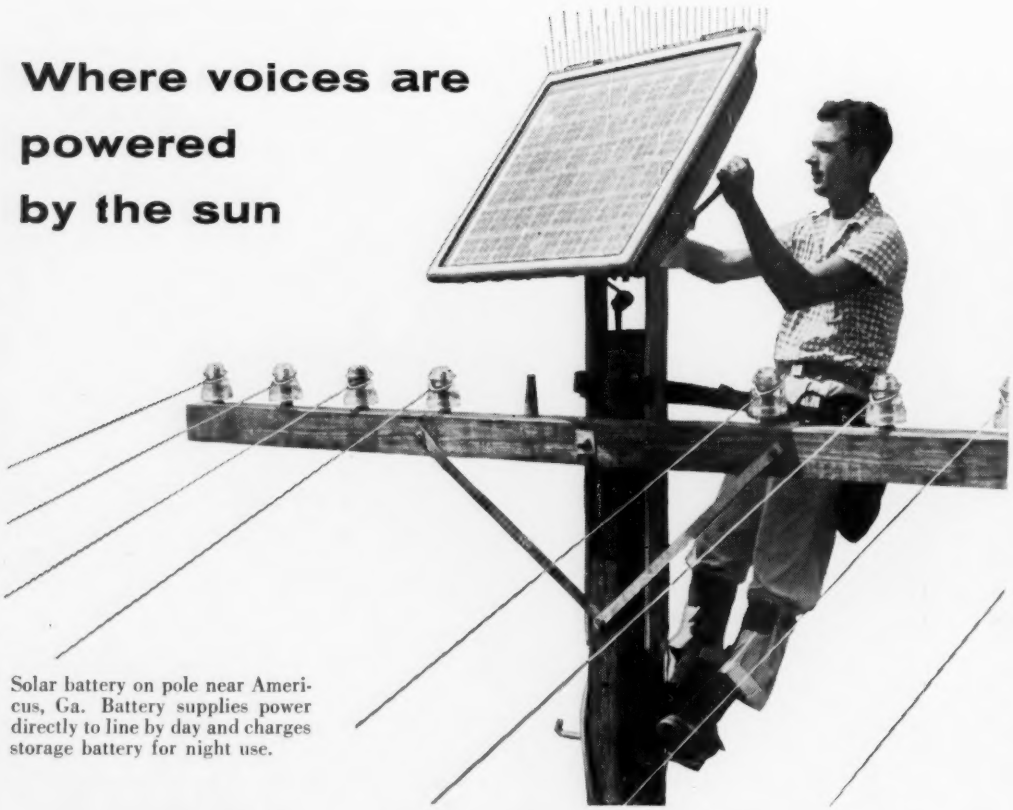
The SCIENTIFIC MONTHLY

VOL. 82 NO. 1 JANUARY 1956

Where voices are powered by the sun



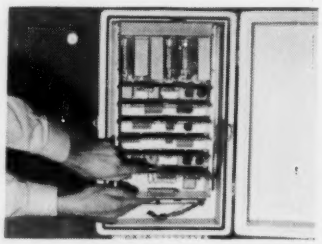
Solar battery on pole near Americus, Ga. Battery supplies power directly to line by day and charges storage battery for night use.

A new kind of telephone system developed by Bell Telephone Laboratories for rural areas is being operated experimentally by electric current derived from sunlight. Electric current is generated as sunlight falls on the Bell Solar Battery, which a lineman is seen adjusting.

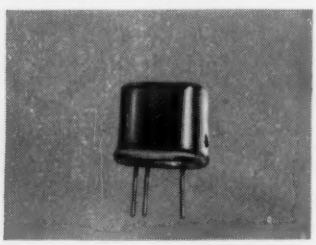
The exciting achievement is made possible by two Laboratories inventions—the solar battery and the transistor. The new system uses transistors to the complete exclusion of electron tubes. Transistors require little power and this power can be easily supplied by the solar battery.

Compact and economical, the system can carry several voices simultaneously without interference. It has proved its ruggedness by standing up to heat, cold, rain and lightning.

It promises more and improved telephone service for rural areas and it typifies the Laboratories' continuing efforts to make American telephony ever better.



In sending and receiving terminals, transistors are used as oscillators, amplifiers and regulators, and for signaling.



One of the transistors (actual size) used in the new system. The project called for new ideas, equipment, tools and methods.

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[*Courtesy The Franklin Institute of the State of Pennsylvania, see page 24*]

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Science and Technology

(From the month's news releases; publication here does not constitute endorsement.)

Glassworking Equipment Catalog

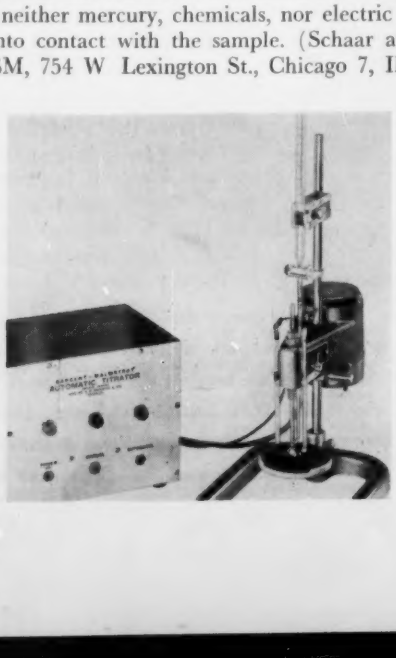
Lab-Lathe, a general-purpose glassworking machine, and its accessories, together with other glassworking equipment, are described in a new glassworking equipment catalog. Section 2 of the catalog is devoted to mercury, mercury cleaning apparatus, and a mercury vapor detector. Technical articles on the Lab-Lathe and on mercury are included. Catalog 54. (Bethlehem Apparatus Co., Inc., Dept. SM, Hellertown, Pa.)

Direct Current Amplifier

Push-pull input and output circuits with input impedance of 100 Mohm and grid current of 10^{-2} μamp, band pass flat to 50 kcy/sec, and four bandwidths that may be selected from the front panel are available in a new direct-current amplifier. Sensitivity may be varied by means of a calibrated attenuator with a maximum gain of 100 db. Drift obtainable is 5 μv/min or less. In-phase signal rejection is adjustable to 50,000 to 1. Noise level is 10 μv root-mean-square at full bandwidth. (American Electronic Laboratories, Inc., Dept. SM, 641 Arch St., Philadelphia 6, Pa.)

Fraction Collector

Automatic collections of fractions for chromatography, by either the timed-flow or the volumetric method, can be made with Schaar's new fraction collector. Since support is furnished at the bottom of the tubes, both culture and lipped tubes may be used for collection. Three interchangeable receiver tables, which are equipped with mounting holes for an indexer, are available. An electronic timer-controller that is capable of indexing each tube to receive fractions on a timed-flow basis from 18 sec to 2 hr is also available. The instrument is designed so that neither mercury, chemicals, nor electric current come into contact with the sample. (Schaar and Co., Dept. SM, 754 W Lexington St., Chicago 7, Ill.)



R-C Oscillator

Square-wave output, in addition to two sine-wave outputs, over a frequency range from 20 cy/sec to 500 kcy/sec is included in R-C Oscillator type 1210-B. Square-wave output is 30 v peak-to-peak, rise time is about 0.25 μsec, and output impedance is 2500 ohms. Automatic recording of frequency characteristics on either a pen recorder or a cathode-ray oscillograph is made possible by a gear-driven precision dial that may be driven automatically by a type 908-P synchronous dial drive. The motor can sweep any portion of each of the five decade frequency ranges. Frequency calibration accuracy is ±3 percent. The logarithmic output control is calibrated from 0 to −50 db. (General Radio Co., Dept. SM, 275 Massachusetts Ave., Cambridge 39, Mass.)

Automatic Separatory Funnel

VirTis Extracto-Matic is an automatic separatory funnel that consists of a stainless-steel box-type stand that houses a heavy-duty electric motor. Motor drives a rocker arm to which eight specially designed Pyrex separatory funnels may be clamped. Rocker arm swings up and down through a 90° arc at a rate of 20 oscillations/min. The separatory funnels do not require stoppers, for the fluid openings always remain above the solution level. Solution is inserted when the separatory funnels are in the horizonal position; fluid can be drained through a precision-ground stopcock when the funnels are in the vertical position. (E. Machlett and Son, Dept. SM, 220 E. 23 St., New York 10)

Metallurgical Microscope

A new metallurgical microscope has an oversized focusing stage with interchangeable stage plates, a fine-adjustment focusing knob located at table level, and an accessory lens for concentrating external illumination into the microscope for photomicrographic work. A new vertical illuminator and triple-revolving objective turret that makes possible the study of opaque or semiopaque specimens in brightfield, darkfield, or polarized light is also available. Literature D-1053. (Bausch and Lomb Optical Co., Dept. SM, 635 St. Paul St., Rochester, N.Y.)

Bottle Stopper Clamp

Normal use of glass tubing is possible with a newly marketed bottle stopper clamp. Cast aluminum clamp, which has a hinged U-shaped upper arm, fits most small bottles that use No. 8 or No. 10 stoppers. (Central Scientific Co., Dept. SM, 1700 Irving Park Rd., Chicago 13, Ill.)

Air-Well Bath

An air-well bath has been designed for the detection of free and corrosive sulfur compounds in aviation gasoline, motor gasoline, cleaner' solvent, fuel oil, and certain other petroleum products. The apparatus consists of a constant-temperature bath and a constant-level device with a steam-tight cover and four air wells. Each of the air wells has a glass condenser mounted on a cork disk. Cover construction is of stainless steel; all fittings are chrome plated. Thermostatic control, heater, and all wiring are mounted in an accessible control compartment. (Modern Laboratory Equipment Co., Inc., Dept. SM, 1809 First Ave., New York 28, N.Y.)

Gas Density Balance

Density of a sample gas is measured by a null balance principle in a new gas density balance. A small dumbbell is supported on a horizontal quartz fiber. One ball of the dumbbell is punctured so that it will not experience buoyancy effects. The other ball tends to change position as the density of the gas changes, creating a rotational force about the quartz fiber that is proportional to the density of the gas. The dumbbell is metal coated and is held in place by an electrostatic force that is established by adjacent electrodes. When the dumbbell rotates, it is restored to its null position by the application of a balancing potential to the electrodes. The balancing potential, which is also proportional to the density of the gas, may be used to operate a meter or recorder. Sensitivity and accuracy are each 0.5 percent of full scale; a 95-percent response is obtained in less than 1 min. Bulletin 118. (Arnold O. Beckman, Inc., Dept. SM, 1020 Mission St., South Pasadena, Calif.)

Periodic Chart of Elements

The new edition of Fisher's simplified periodic chart of the elements is printed on Texoprint, a combination of fiber and plastic that is washable and that will not curl, flake, or fray. The chart shows symbol, atomic number, atomic weight, and group for each element, as well as maximum orbital electron distribution for each period. The lanthanum and actinium series are separated from the other elements. Type is black and red, and the chart measures 23 by 32 in. (Fisher Scientific, Dept. SM, 717 Forbes St., Pittsburgh 19, Pa.)

Resolution Test Patterns

Designed for use in determining the resolving power of photographic lenses and other equipment and in determining the relative performance of lenses, various resolution test patterns on glass are available singly or in quantity. Bulletin 8000. (W. and L. E. Gurley, Industrial Div., Dept. SM, Troy, N.Y.)

Cold Cathode Counting Tube

Type GS12D cold cathode counting tube has 12 cathodes brought out to pins on the 13-pin base. Positive voltage is available on the glowing cathode. Counting rate is 0 to 4000 pulses/sec. Tube is 3.49 in. long, bulb diameter is 1.3 in., and base diameter is 1.39 in. Anode current is 0.35 ma maximum; supply voltage is 350 v; and maximum voltage between electrodes, other than anode, is 140 v. (Atomic Instrument Co., Dept. SM, 84 Massachusetts Ave., Cambridge 39, Mass.)

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Resistance Precision Meter

Over-all range of a new precision resistance meter is 0.01 ohm to 100 Mohm in seven individual ranges. Accuracy is ± 0.1 percent ± 1 mohm in the ranges from 0.01 ohm to 10 Mohm and ± 0.5 percent in the range from 10 to 100 Mohm. Load on the unknown is less than 10 mw. (Instrument Div., Federal Telephone and Radio Co., Dept. SM, 100 Kingsland Rd., Clifton, N.J.)

Inverted Spectrograph

Designed so that the x ray beam strikes specimens from the bottom, a new inverted spectrograph may be used for analysis of metals, powders, and liquids. Three specimen holders fit into a horizontal disk that rotates inside a leaded-bronze housing. Disk shaft extends through the top of the housing to a control knob. Specimen holders have ¼-mil thick Mylar windows that are held in place with retaining rings. A nickel-foil collimator with ⅛-in. spacing is built into the instrument. (Research and Control Instruments Div., North American Philips Co., Inc., Dept. SM, 750 S. Fulton Ave., Mount Vernon, N.Y.)

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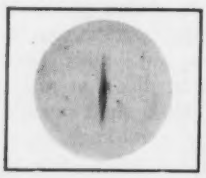
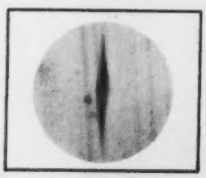
18-4-2 steel

Photomicrographs above show results of Knoop hardness test on Kennametal K8 and HSS 18-4-2 steel at 100g. Impression in the Kennametal is only about half of that on the steel.



Tungsten-titanium carbide



Tungsten carbide

Photomicrographs at left are of Knoop tests on grains of carbide ingredient of Kennametal. Knoop test numbers (at 100g) are: Tungsten carbide, 1900; tungsten-titanium carbide, 2200; titanium carbide, 2500. These tests show those carbides are from two to three times as hard as steel in the absolute scale of Kgs per square mm of area of impression.

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THE
SCIENTIFIC MONTHLY

JANUARY 1956

Recent Developments in the Detection and Measurement of Infrared Radiation

R. A. SMITH

Dr. Smith is head of the physics department at the Radar Research Establishment, Malvern, England. He received his training at the universities of Edinburgh and Cambridge and afterward held a number of university appointments. He joined the staff of the Radar Research Establishment at the outbreak of World War II and carried out research on a number of radar projects in which he had close association with the staff of the Radiation Laboratory at Massachusetts Institute of Technology. Since the war, his laboratory has been concerned with solid-state physics and advanced microwave techniques, particularly transistor physics and infrared techniques.

FOR many years after the discovery of the infrared spectrum by William Herschel (*1*) in 1800, the only methods available for the observation and study of the radiation depended on its heating effect. Indeed, the rather slow development of infrared spectroscopy has been largely the result of the lack of detectors having the speed and sensitivity of those available for visible light. The photographic plate and the human eye have been the detectors most widely used for the latter, but they have, within the last 25 years or so, been supplemented by the photoemissive cell and more recently by the photomultiplier.

Herschel himself for the most part used mercury-in-glass thermometers to study infrared radiation and indeed discovered it by moving such a thermometer beyond the red end of a solar prismatic spectrum and noting that the mercury continued to rise. His original paper is a fine example of beautiful scientific writing and is full of the joy and wonder of a new discovery. His son, John Herschel (*2*), was able to show an infrared spectrum visually by making use of differential evaporation owing to the heating power of the radiation. He used a piece of paper coated with lampblack and soaked in alcohol. The evaporation of the alcohol showed up dark patches where the radiation was most intense.

It was not, however, until electric methods of measurement were introduced by Melloni (*3*) about 1833 that rapid progress was made. Melloni used a radiation thermocouple; this became the standard instrument for the detection and measurement of infrared radiation and was used for many years. It had no serious competitor until Langley (*4*) introduced the bolometer in 1880. For many years thereafter the thermocouple and bolometer were close competitors for first place as infrared detectors; a very great deal of work has gone into their development and improvement.

The next major advance in observation technique was the development of the infrared photographic plate. Although photographic effects in the

infrared had been observed since about 1843, particularly by E. Becquerel (*5*), these were confined to the region of the spectrum that is very close to the visible. Becquerel also discovered another very interesting phenomenon, the quenching and stimulation of phosphorescence by infrared radiation. This phenomenon has been used in recent times as the basis of some infrared image converters.

For half a century after Becquerel's early work, various experimenters found photographic effects and indeed succeeded in some measure in photographing spectra in the near infrared. It was not, however, until about 1919, when near-infrared sensitization was introduced as a further development of the panchromatic plate, that infrared photography came to be extensively used. Various new sensitizers were introduced in turn and enabled spectra to be photographed with exposure times comparable with those for visible light to a wavelength of about 0.9 micron and with reduced sensitivity to about 1.3 microns. Beyond this wavelength, however, the photographic sensitivity is negligible; because many of the most interesting infrared spectra occur at longer wavelengths, the thermocouple and bolometer remained the best infrared detectors for most purposes.

With the advent of the photoemissive cell, a new detector became available for visible radiation. It combined high sensitivity with extreme rapidity of response. Unfortunately, suitable photocathodes for the infrared are not easy to make and in any case are limited in sensitivity to about the same range as the photographic plate. It may therefore be said that until the advent of the modern photoconductive cell there had been no major advance for many years in detection of infrared radiation for wavelengths beyond about 1.3 microns, apart from some modern developments that increased the speed of response of bolometers and thermocouples.

The photoconductive cell has, however, radically changed this situation, and fast sensitive detectors are now available for wavelengths up to about 8 microns. These detectors use the following lead salts: lead sulfide, lead telluride, and lead selenide. Cells using lead sulfide and sensitive at room temperature to about 3 microns are now readily available commercially. So far, lead telluride and lead selenide cells have been made only in small quantities. A number of these cells, particularly the lead telluride cells, have been made in our laboratory and have been used by spectroscopists in several countries to obtain high-resolution infrared spectra with speed and sensitivity very considerably greater than the speed and sensitivity previously available. Typical of this work is that of H. W. Thompson and his colleagues at Oxford who have used our cells to resolve complex spectra in the infrared and to study in detail the fine structure of bands (*6*).

The main object of this article is to give an account of the development of these photoconductive detectors and to indicate the fundamental physics research that has been necessary in order to try to understand details of their operation (*7*). In particular, I have discussed the properties of the extremely interesting group of semiconductors—lead sulfide, lead telluride, and lead selenide—that form the sensitive elements of these detectors.

At present there seems to be no immediate prospect of extending detection to much longer wavelengths by means of these and allied substances. Recent observations (*8*) of photoconductivity in specially "doped" samples of germanium and silicon cooled to low temperatures give some hope that photoelectric methods of detection may be developed in the future for considerably longer wavelengths than those for which they are now available. At the moment, for wavelengths beyond about 8 microns, one must use a thermal detector such as a thermocouple, bolometer, or the more recently introduced Golay cell (*9*).

One great advantage of the photodetector over the thermal detector is vastly increased speed. By using a lead telluride cell and automatic recording techniques, spectra have been obtained in a few seconds (*10*) that only a few years ago took several hours of laborious plotting, point by point, of readings obtained with a sluggish thermocouple or bolometer.

In order, therefore, to appreciate the full significance of the advance made through the introduction of the photoconductive detectors, we must consider very briefly the limitations of the thermal detectors—limitations which there are good reasons for believing will prevent any major improvement in performance over what has already been achieved.

Thermal Detectors

There have been, in recent years, a number of reviews of the development of infrared detectors (*11, 12*) that have dealt extensively with thermal detectors; for this reason, I do not propose to treat the subject in any detail. Langley (*4*) and his followers had made the bolometer into a very sensitive instrument, but it required a high degree of skill in the experimenter, and much patience, to obtain the best results. It was sluggish in operation and required careful use of potentiometric methods, depending as it does on the measurement of a very small change of resistance in the sensitive element caused by heating owing to the radiation. In the hands of W. W. Coblenz (*13*), the radiation ther-

mocouple, as used with a steady flux, was brought to a high degree of perfection. Both these instruments required the use of a very sensitive galvanometer when they were operated at their limit of sensitivity. Various other special forms of thermal detector such as the radiomicrometer were also introduced, but they fell into disfavor because they were too fragile and required too much delicate adjustment.

With the advent of electronic amplifiers, it at once became clear that an enormous advantage would be gained if the amplifiers could be made to replace the very delicate, sensitive galvanometers in use with thermocouples and bolometers. We may note here that it is not easy, but that it is possible, to design a galvanometer whose ultimate sensitivity is set by the fundamental thermal fluctuations to which all measuring instruments are subject. Such an instrument is, however, very delicate and subject to external disturbances such as vibration. On the other hand, it is relatively easy to make an electronic amplifier whose output shows the fundamental electric fluctuations (Johnson noise) in the input circuit. The limitation set by such an amplifier, is, then, a fundamental one, and the sensitivity is as high as is physically achievable. It therefore seemed possible that, by using an electronic amplifier to magnify the small voltage output from a bolometer or thermocouple, it would be fairly easy with a simple and robust piece of apparatus to reach the ultimate limits of sensitivity set by the random electric fluctuations in the sensitive elements of the bolometers or thermocouples themselves, and not be limited by the measuring instrument. Unfortunately, when such amplifiers came to be used with thermocouples and bolometers, a very serious difficulty arose.

Although it is fairly easy to make such an amplifier for alternating current, it cannot readily be done for a direct-current amplifier. It therefore became common practice to "chop" the radiation incident on the detector and to amplify the resulting alternating signal from the detector. It soon became apparent that conventional thermocouples and bolometers are far too sluggish for this use. The lowest frequency for which alternating-current amplifiers can readily be made so as to reach a limit set by fundamental fluctuations is about 5 cycles per second. Even at this frequency, the sensitivity of response of conventional thermocouples and bolometers was found to be very much down on their direct-current response. As a consequence, most of the modern work on thermocouples and bolometers has been directed toward reducing their response time while retaining their high sensitivity.

This work has been highly successful, and various workers such as Hornig and O'Keefe (*14*) have made instruments that retain their full performance at a frequency of 5 cycles per second; this performance is very nearly as good as is theoretically possible. With the introduction of the Hilger-Schwarz (*15*) thermocouple based on semiconducting materials, a reasonably robust instrument has become available whose sensitivity is also very nearly as good as can be obtained with known materials and which can be operated at a frequency of 5 cycles per second or slightly higher. Any considerable increase in frequency is not possible without serious loss of sensitivity. The very best thermocouples can, with careful attention to all parts of the associated electronic equipment, and in particular to the design of the input transformer, detect a minimum incident power of about 10^{-10} watt at a frequency of 5 cycles per second with a 1-cycle-per-second bandwidth. In practice, however, in our experience, commercial couples used under ordinary laboratory conditions give a minimum detectable power with this frequency and bandwidth not much less than 10^{-9} watt. With a thermocouple having, as is usual, an effective receiver area of about 1 square millimeter, this would correspond to a flux of 10^{-7} watt per square centimeter.

Bolometers having a similar ultimate sensitivity have also been developed; they may be used with even higher chopping frequencies but are not generally so constant in their properties as the best thermocouples. They suffer from a form of "noise" that results from the steady current that must flow through the sensitive element in order to show up the change of resistance. This so-called "current noise" increases rapidly at the lower frequencies, so again a rapid response is very advantageous.

The response time of a bolometer or thermocouple is set by its thermal capacity and the thermal impedance of the sensitive element to its surroundings. The latter must be kept high to obtain high sensitivity of response. The former cannot be indefinitely reduced, for very thin films no longer show the properties of the bulk materials from which they are made. Indeed, a limit has now been reached and further reduction in the thermal capacity of bolometers and thermocouples is unlikely.

For a photodetector, on the other hand, the thermal capacity is immaterial. The speed of response depends solely on the photoelectric properties of the detector. For a photoemissive detector, it is set mainly by the transit time of electrons from the cathode to the anode and will, in general, be a small fraction of a microsecond. For a photoconductive detector, it is set by the mean lifetime of the extra current carriers that are generated by the incident radiation. In practical detectors, this

can be made to vary from about 1 to 1000 microseconds. Thus we see that there is an enormous gain in the speed of response of the photodetectors. As we shall see, we also gain in ultimate sensitivity.

Before concluding this section I must mention two modern developments of thermal detectors. The first is the superconducting bolometer described by D. H. Andrews and his colleagues (*16*). By use of a low temperature, in the liquid hydrogen range, and the very rapid change of resistance that results from the onset of superconductivity of a sensitive element made of niobium nitride, both a reduction in thermal capacity and an increase in sensitivity of response are obtained. The result is a very sensitive bolometer capable of detecting at least 10^{-11} watt of incident power per cycle bandwidth, with an element of area 1 square millimeter and operating at a frequency of 300 cycles per second. The superconducting bolometer can hardly be classed, however, as an instrument for general laboratory use.

The second development is a pneumatic detector known as the Golay cell (*9*). In sensitivity it is comparable with the thermocouple and it is now a serious rival for use at wavelengths longer than those that can be reached with photoconductive detectors. Because it has a rather delicate optical lever arrangement for amplifying the small movements caused by the increased pressure owing to heating of the gas in the sensitive element, it suffers from microphony, but if it is used with care, it is a very useful detector. Its frequency response is similar to that of a modern thermocouple.

Photoconductive Infrared Detectors

Having seen the great advantages to be obtained with photodetectors, we shall now follow their development, which has taken place largely during the past decade. Photoemissive infrared detectors have not been much used, for they are applicable only to the near infrared. They have, however, been used recently with success in certain astrophysical applications, and very high sensitivities have been obtained—for example by Kron (*17*)—in the wavelength range 0.8 to 0.9 micron. Moreover, the silver-cesium oxide photocathode, which is sensitive in the near infrared, has formed the basis for certain forms of infrared image converter. These converters enable an infrared image to be made visible, usually as a television-type picture on a cathode-ray tube. Since these cathodes are sensitive only in the near infrared, the subject being viewed must generally be illuminated by a powerful infrared source, for the natural radiation from bodies at ordinary temperatures contains insufficient near-infrared radiation to operate such a converter. Military applications of image converters as used in World War II have been discussed by Elliott (*18*).

By far the most important effect of which use is now made to provide infrared detectors is photoconductivity—an increase of conductivity on illumination without appreciable change of temperature. This effect should not be confused with the bolometric effect, which results from the heating of the sensitive element. In metals, the conductivity decreases on heating, but in substances known as semiconductors it may increase, thus making the bolometric effect more difficult to distinguish from true photoconductivity. The photoconductive process is a "single quantum" effect and does not depend on a change of temperature. This effect has been known for a long time. Unfortunately, very few substances show the effect in a marked fashion in the infrared, although a great many do so when they are illuminated by visible light or ultraviolet radiation. I have discussed in a subsequent paragraph the conditions that lead to infrared photoconductivity.

Photoconductivity may be regarded as a kind of internal photoelectric effect in which electrons are excited by the incident radiation to become mobile charge carriers, but remain within the solid. In photoemission the electrons are ejected from the surface of the solid. Infrared photoconductivity has been known since about the end of the 19th century, but it was not until about 1917 that it was used as the basis of an infrared detector. In the course of an investigation of photoconductivity, T. W. Case (*19*) found many natural minerals that showed the effect in the infrared. Later, using thallium sulfide, Case (*20*) developed an oxidation process, that greatly increased the photoconductive sensitivity and enabled a detector to be made whose sensitivity was comparable with that of a good thermocouple, and with a vastly shorter response time. Such detectors were known as "thalofide cells." They were further developed during World War II with a view to possible military applications—in the United States by R. J. Cashman (*21*), and also in England. Unfortunately, their sensitivity extends only to a wavelength of about 1.3 microns and they have now been completely replaced by the lead salt photoconductive cells. Therefore, I have not discussed them further. We should note, however, that the thallium sulfide cell represented a major advance in infrared detection technique.

A great deal of work was carried out in Germany during World War II on lead salt photoconductors. Lead sulfide, lead telluride, and lead selenide were all studied, but only photocells made from lead

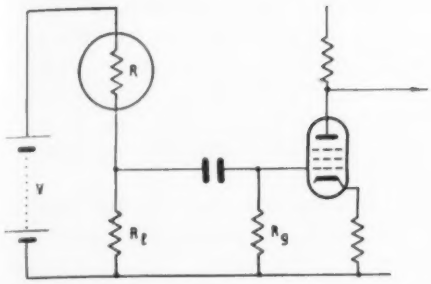

Fig. 1. Arrangement of photoconductive cell with alternating-current amplifier.

sulfide were used to any extent for military applications. In addition to the photoconductive effect, a photovoltaic effect was also used. When a thin layer of lead sulfide, suitably sensitized, is illuminated, an open-circuit voltage appears across it that can be made the basis of detection. The straightforward photoconductive effect is now almost universally used instead. The great advantage of lead sulfide over thallium sulfide is that its marked photoconductive sensitivity exists to about 3 microns at room temperature and can be extended to just beyond 4 microns by cooling to the temperature of liquid air. Later developments were the lead telluride cell, which is sensitive to just beyond 5 microns, and the lead selenide cell, which is sensitive to nearly 8 microns.

Photoconductive Cells and Electronic Amplifiers

When infrared radiation suddenly falls on a photoconductor, the conductor's resistance drops rapidly to a lower value. When the radiation is removed, the resistance then returns to its former value. The magnitude of the effect is quite marked. For example, the radiation from a soldering iron that is held near a sensitive lead sulfide layer will easily halve the resistance of the layer. The time constant associated with the drop and return of resistance is a characteristic of the layer. For lead sulfide, it may vary from about 1 to 1000 microseconds. As we have seen in a previous paragraph, it is desirable to chop the radiation incident on the photocell, and in marked contrast to the older types of detector, these cells permit the use of fairly high chopping frequencies. This greatly eases the problems of amplifier design. It is fairly common in the United States to use a chopping frequency of 90 cycles per second, whereas in the United Kingdom it is more usual to use 800 cycles per second; however, there is nothing "magic" in the exact value of the frequency. The photocell is connected to the amplifier as shown in Fig. 1. A battery supplies a steady voltage V across the cell, whose resistance is R, and a load resistance R_e in series with it. The junction of cell and load resistance is connected through a condenser to the grid of the first electron tube of a narrow-bandwidth amplifier that is tuned to the chopping frequency. The cell resistance is usually of the order of 1 megohm and the load resistance about 0.1 megohm; hence there is no need to use a transformer, as there is for a detector such as a thermocouple.

If the incident radiation causes a small change ΔR in R, the signal voltage V_s appearing at the output will be given by

$$V_s = \frac{R_e\, i\, \Delta R}{R + R_e} \qquad (1)$$

where i is the steady current through the cell. For small radiation intensities such that $\Delta R \ll R$, it is found that ΔR is proportional to the intensity I of the radiation falling on the sensitive element. If I is varied sinusoidally, then ΔR will also vary sinusoidally with the same frequency, and an alternating voltage will appear at the input of the amplifier. In fact it is not necessary to arrange for a precise sinusoidal variation of the incident radiation intensity. Since the amplifier in use generally has a narrow bandwidth in order to reduce fluctuation noise, it will select the fundamental chopping frequency and reject higher harmonics. Thus a rotating sector disk is normally used for chopping the radiation.

When the photocell is used in conjunction with a spectrometer, an arrangement of the form shown in Fig. 2 is employed. A rotating sector disk chops the radiation from the source before it goes through the entrance slit, on which it is focused by means of a mirror. The emergent radiation is also focused on the sensitive element of the cell by means of a mirror. When the highest sensitivity is desired, a phase-sensitive type of amplifier may be used with considerable advantage (22), the reference phase being obtained from the rotating chopper shaft.

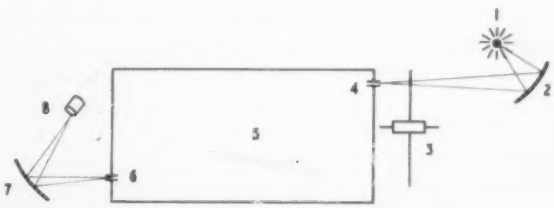

Fig. 2. Use of photoconductive cell with a spectrometer. *1*, source of infrared radiation; *2*, mirror giving image of source on entrance slit; *3*, chopping disk; *4*, entrance slit; *5*, spectrometer; *6*, exit slit; *7*, mirror focusing emergent radiation on detector; *8*, detector.

Lead Sulfide Cells

The infrared photoconductivity of lead sulfide has been known since about 1901, but it was only after 1939 that lead sulfide was used as the basis of a sensitive infrared detector. This resulted from the observation that thin layers of lead sulfide, either evaporated in a vacuum or deposited chemically, when treated with oxygen, had their sensitivity to infrared radiation enormously increased. Photoconductive detectors using lead sulfide are still made in this way and the commercial cells available are of two distinct types—chemical and evaporated. The chemical cells are made by depositing from solution a thin layer of lead sulfide on an insulating substrate such as mica, on which conducting electrodes have previously been deposited. These may be either metallic or of graphite painted on in the form of aquadag. After deposition, the layer may be further treated with oxygen; it may also be partially oxidized during deposition. It is then simply protected by a thin transparent sealing layer. Such a detector is illustrated on the left in Fig. 3. The space between the electrodes is generally rectangular in shape, about 1 centimeter long and 1 millimeter wide. This shape is convenient for receiving the focused image of the output slit of a spectrometer.

The evaporated-layer cells are made by first placing a small quantity of lead sulfide in a glass envelope of the shape shown on the right in Fig. 3. The envelope is then evacuated and the lead sulfide transferred, by heating, to the inner surface on which electrodes have previously been painted. Connections to these electrodes are made through pinches. The deposited layer is next treated with oxygen until a high sensitivity is achieved. The cell is then sealed off. Various workers have developed their own particular processes for sensitizing the cells. I have recently reviewed the subject (*23*) and do not propose to go into methods of processing the cells in this article. Both types of cell show the same form of spectral response. A typical response curve for constant energy flux per unit wavelength increment is shown in Fig. 4. It will be seen that the response is a maximum at about 2.7 microns and falls off slowly toward the short-wave end of the spectrum. If the response is plotted for a constant number of incident quanta instead of for constant energy flux, very little variation is found. This indicates an approximately constant quantum efficiency up to a wavelength of about 2.7 microns. For longer wavelengths the response falls rapidly, reaching half its maximum value at about 2.9 microns and 1 percent at about 3.3 microns.

Fig. 3. Uncooled lead sulfide infrared cells. Left, chemical cell; right, evaporated-layer cell.

There are some advantages for both types of cell. The chemical cells are more compact and are probably easier to manufacture. They may deteriorate, however, if the protecting layer is damaged. Their time constants seem to vary between about 50 and 500 microseconds. They are more commonly used in the United States than they are in the United Kingdom—chiefly because of their availability—and a chopping frequency of 90 cycles per second is generally suitable. The evaporated-layer cells generally have time constants between 5 and 100 microseconds, although cells have been made with time constants as low as 1 microsecond. In spite of the shorter time constants, there seems to be an indication that the evaporated-layer cells have a slightly higher ultimate sensitivity. They are normally used with a chopping frequency of about 800 cycles per second. Both types of cell are commercially available in the United States but, at present, only evaporated-layer cells are marketed in the United Kingdom.

There are very few data on the actual values of ultimate sensitivity available from the commercial cells, but the sensitivity would appear to correspond to a minimum detectable monochromatic power with a 1-cycle-per-second bandwidth varying from about 10^{-10} to 2×10^{-11} watt for a cell of effective area of 0.1 square centimeter. Figures have been quoted by various research workers who have made individual cells in the laboratory that indicate that somewhat greater sensitivities can be achieved with hand-made picked cells.

Particularly with evaporated-layer cells, it is found that a considerable gain in ultimate sensitivity is obtained by cooling the layer. In general, for lead sulfide, no further increase in ultimate sensitivity is obtained if it is cooled below the temperature obtained with solid carbon dioxide, although an added advantage of an extension of the available spectrum is obtained by further cooling to the temperature of liquid air. The lead salts—lead sulfide, lead selenide, and lead telluride—have the almost unique property among photoconductors that the long-wave limit of response moves out to longer wavelengths on cooling—a very fortunate circumstance, as it turns out. Thus, if a lead sulfide cell is cooled by means of liquid air, the useful response is extended to beyond 4 microns. The form of re-

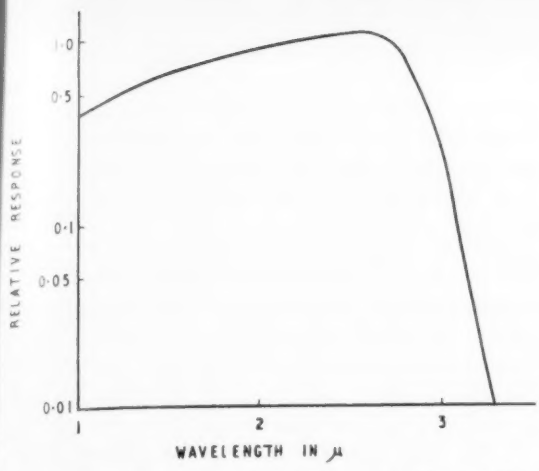

Fig. 4. Spectral response of typical uncooled lead sulfide photoconductive cell.

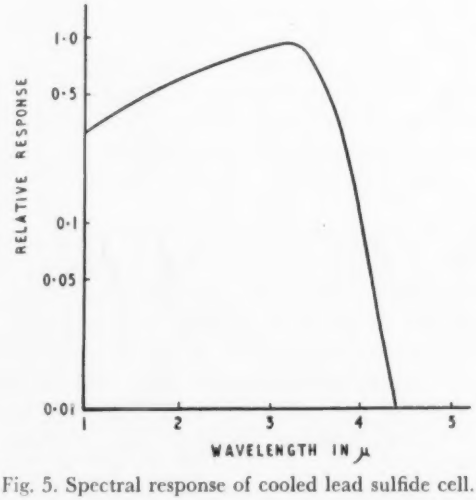

Fig. 5. Spectral response of cooled lead sulfide cell.

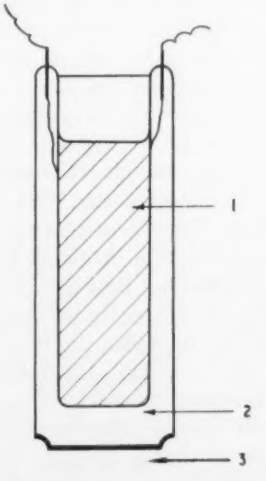

Fig. 6. Form of construction for a coolable cell. *1*, coolant; *2*, sensitive layer; *3*, window.

sponse for a typical cooled lead sulfide cell is shown in Fig. 5. It may be seen that the maximum of the response occurs at about 3.3 microns. It falls to half its maximum value at about 3.7 microns and to 1 percent at about 4.4 microns.

Coolable cells are usually made in the evaporated-layer form. The envelope is made as a small Dewar vessel, as shown in Fig. 6. The space between the outer and inner glass walls is evacuated and provides thermal insulation for the coolant as well as protection for the sensitive layer. The sensitive layer is deposited on the surface of the inner wall. Because of the extension of the spectral response, it is usual to provide the cell with a quartz or thin bubble window, for hard glass becomes opaque at wavelengths beyond about 3.7 microns.

Very few data are available on the ultimate sensitivity achievable with a cooled lead sulfide cell. Various users have quoted a figure of "about 1000 times better than an average thermocouple" for minimum detectable power, which would lead one to expect a value of about 10^{-12} watt for a 1-cycle-per-second bandwidth. For a cell of effective area of 0.1 square centimeter, this would correspond to a flux of 10^{-11} watt per square centimeter. Fellgett (*24*) has in fact quoted one figure of 4.9×10^{-13} watt for a cell of effective area of 0.2 square centimeter that is cooled with solid carbon dioxide, so this estimate is not far wrong. He has shown, moreover, that this value is not very far short of what is the optimum theoretically achievable. The background radiation falling on the cell is in the form of quanta that arrive in a random fashion and cause fluctuations in the output in exactly the same way as the shot noise in an electron tube is produced. These radiation fluctuations set the limit in an ideal detector—a limit beyond which ultimate sensitivity cannot be improved (*23*). For a lead sulfide cell of area 0.1 square centimeter and cooled with solid carbon dioxide, the limit set by radiation fluctuations corresponds to a minimum detectable power of about 3.5×10^{-13} watt for 1-cycle-per-second bandwidth. In practice, apart from the figure for exceptional cells such as that quoted by Fellgett, the limit is set by the noise generated by the steady exciting current flowing through the cell.

These considerations show that one may go even further in cooling the cell. The background radiation falling on the sensitive layer arises mainly from the outer glass walls of the cell, which are at room temperature, and also from the external radiation to which they are transparent. By silvering the outside walls and leaving only a narrow slit as an entrance for the wanted radiation, and then cooling them all to liquid-air temperature by means of a vessel having a double Dewar flask construction,

the layer can be screened from most of the room-temperature background radiation. The radiation from the cooled surfaces is, of course, greatly reduced compared with that from the same surfaces at room temperature. The background radiation falling on the sensitive layer from the surroundings is therefore greatly reduced. This, in turn, gives a considerable increase in the steady-state resistance of the layer since, being photoconductive, the layer is sensitive to the component of the background radiation with wavelengths less than 4 microns. This is only a small fraction of the background radiation, but that it is quite effective is evidenced by the fact that a resistance increase of the order of 100 times is sometimes found when it is screened off. The decrease in background radiation leads to reduced radiation fluctuations and, what is more important, to reduced current noise. A considerable increase in ultimate sensitivity results; a figure of 2×10^{-14} watt has been quoted by Watts (*25*) for a cell of effective area of 0.1 square centimeter. This more complicated form of construction is used only when the very highest sensitivity is required; the ordinary carbon dioxide- or liquid-air-cooled cell is generally used for high-resolution spectroscopy. For many uses an uncooled cell is quite adequate.

An interesting relationship between time constant and sensitivity of response has been found by McAlister and discussed by R. C. Jones (*12*). It appears that there is a direct proportionality between the signal response obtainable and the time constant. If the noise output varies little with time constant, as appears to be the case, then the minimum detectable power should also be inversely proportional to the time constant. This does in fact appear to be true for cells made by one process, but the constant of proportionality is different for different processes. For example, some evaporated-layer cells have much shorter time constants than chemical cells, but they are also more sensitive.

The values quoted for the minimum detectable power refer to monochromatic radiation whose wavelength corresponds to the maximum in the spectral response. For black-body radiation, the minimum detectable power depends on the temperature of the source, for the fraction of the radiation to which the cell is sensitive is a function of the temperature of the source. For a source at 500°K such as is commonly used for testing cells, the values given should be multiplied by a factor 0.011 for an uncooled cell and by 0.054 for a cell cooled with liquid air.

Cooled lead sulfide cells have now been used by a number of spectroscopists to increase the resolution obtained in the spectral region of 1 to 4 microns by a very substantial amount. Typical of this work is that carried out recently by Goldberg and his associates at the McMath-Hulbert observatory (*26*) on the high-resolution mapping of the infrared solar spectrum for the regions 1.52 to 1.75 microns and 1.97 to 2.49 microns.

Lead Telluride Cells

Photoconductive cells in which lead telluride has been used instead of lead sulfide have been made in small numbers by a number of research workers, but they have not yet, so far as is known, become generally available commercially either in the United Kingdom or in the United States. They have been brought to a high state of development in our laboratory, particularly by A. S. Young, and about 100 or so have now been made for our own use and for distribution to various workers in high-resolution infrared spectroscopy. Reference has already been made to some of the achievements in high-resolution spectroscopy made possible by these cells. They are the most sensitive detectors currently available for the spectral range from 4 to 5 microns, which contains many very interesting infrared spectra.

The lead telluride cells show only very small sensitivity at room temperature and are always used cooled with liquid air. They are made in the Dewar vessel form shown in Fig. 6 and may have either a side window or a window at the bottom. The latter form of cell is much easier to make. The windows for lead telluride cells are generally made from artificial sapphire, which transmits well to beyond 5 microns.

The processes used for making lead telluride cells also vary with the different workers, but they are similar to those used for lead sulfide evaporated-layer cells. So far as is known, no success has been had in the chemical formation of lead telluride layers that have a sensitivity comparable with that of the cells formed by the evaporated-layer method.

Various figures for the ultimate sensitivity of lead telluride cells have been quoted. However, some are quite misleading. They depend very much on the form of spectral response obtained. Cells that peak at short wavelengths but that have a poor response at wavelengths of the order of 5 microns, often show abnormally high sensitivity at the shorter wavelengths. For example, the remarkable figure quoted by Simpson, Sutherland, and Blackwell (*27*) of 2×10^{-14} watt refers to a cell of area 1 square millimeter that peaked at 2.2 microns; it was measured at the maximum of the response. The spectral response of such cells is not at all typi-

cal of modern lead telluride cells such as those made in our laboratory. These have a maximum response at about 4 microns, which falls to half value at about 4.6 microns and reaches 1 percent of its maximum value at 5.6 microns. The form of spectral response of a typical lead telluride cell at 90°K is shown in Fig. 7.

Various users of the Radar Research Establishment cells have expressed their sensitivity as "about 100 times better than an average thermocouple." This would lead one to expect a minimum detectable power of about 10^{-11} watt for a 1-cycle-per-second bandwidth. The average value of the minimum power detectable with a 1-cycle-per-second bandwidth measured recently for a few of these cells, operated at liquid-air temperature, was 2×10^{-11} watt (*28*). Since the cells had an effective area 0.1 square centimeter, this would correspond to a flux of 2×10^{-10} watt per square centimeter. The time constants of the cells vary from about 10 to 50 microseconds. There appears to be no correlation between the value of the time constant and ultimate sensitivity as there is for lead sulfide cells.

Lead telluride layers are even more sensitive than lead sulfide layers to the effect of room-temperature background radiation, and removal of this by use of a double-walled Dewar vessel gives rise to a very considerable increase in the resistance of the layer. This results in a decrease by a factor of ten or so of the minimum detectable power.

To convert the afore-mentioned values of minimum detectable monochromatic power at the maximum of the spectral response to the minimum power from a black-body source at 500°K that is detectable, we must multiply by a factor 0.12, provided that the cell has a spectral response similar to that shown in Fig. 7.

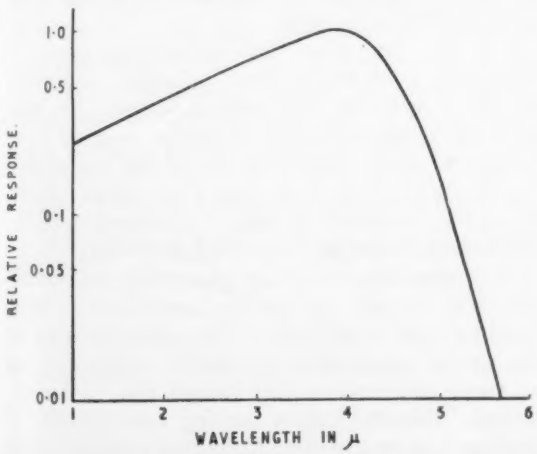

Fig. 7. Spectral response of lead telluride cell at 90°K.

Lead Selenide Cells

Since selenium comes between sulfur and tellurium in the periodic table, it might be reasonable to suppose that the properties of lead selenide would be intermediate between those of lead telluride and lead sulfide. Indeed, early work in lead selenide photoconductive cells (*23*) appeared to indicate that, insofar as photoconductivity is concerned, this was true. There appeared, therefore, to be little point in developing lead selenide cells. Fundamental research on the properties of lead selenide in the form of single crystals showed, however, that the early predictions were wrong. This work is discussed in the next section. It turns out that photoconductivity in lead selenide extends to *longer* wavelengths than it does in lead telluride. Soon after this discovery, a lead selenide cell was made by Gibson, Lawson, and Moss (29) that had a spectral response extending to beyond 7 microns when cooled to liquid-air temperature. At this time it was thought that 5.5 microns was about the limit that could be reached with lead salt photoconductive cells. This discovery opened up a whole new and important range of the infrared spectrum to photoconductive detection.

Lead selenide cells with this increased spectral response have been, so far as is known, developed only in our laboratory. A small number have been made and have been given to various spectroscopists interested particularly in the region of 5 to 7 microns. Roberts and Young (*30*) have shown that these cells are only about 5 times more sensitive than an average thermocouple and that the main advantage in using them lies in their greatly increased speed of response, which permits the use of much simpler associated electronic equipment. For fast automatic recording of spectra they are, of course, invaluable, and Roberts and Young (*30*) have given examples of spectra recorded with fairly good resolution in the remarkably short time of 0.01 second.

The spectral response of a typical modern lead selenide cell as made in our laboratory for operation at liquid-air temperature is shown in Fig. 8. It may be noted that lead selenide cells show some response at room temperature, but it is very much less than their response when they are cooled.

Lead Sulfide Group of Semiconductors

Just as the invention of the transistor has led to a vast amount of fundamental research into the properties of germanium and, more recently, of silicon, so the development of infrared photoconductive cells has stimulated a great deal of interest

in the properties of the group of substances lead sulfide, lead telluride, and lead selenide. These lead salts turn out to be unique in many ways and form an extremely interesting group of solids well worthy of study for their own sake. Like germanium and silicon, they belong to the class of substances called semiconductors. They differ from germanium and silicon in being polar compounds having a cubic crystal structure like that of sodium chloride. The binding is to a large extent ionic, although not wholly so, and to a first approximation we may consider the lead sulfide crystal as made up of Pb^{++} ions and S^{--} ions bound together by their electrostatic attraction. There is a good deal of evidence that there is also some homopolar binding resulting from a sharing of electrons between neighboring ions. The binding in germanium and silicon is, of course, entirely of the latter form. In view of these differences, it is not surprising to find differences between the properties of the lead sulfide group and germanium.

I assume that the reader is familiar with the general properties of semiconductors—namely that they are substances whose valence electrons form a completely filled band of energies at the absolute zero of temperature. They differ from insulators in having a "conduction" band that is separated by only a small forbidden energy gap from the full band. In a semiconductor, this separation is about 1 electron volt or less; for this reason, an appreciable number of electrons may be excited from the full band at ordinary temperatures and can thus take part in conduction. In a good insulator the separation will be at least 5 electron volts. Two processes of conduction of electricity may take place: (i) that owing to motion of electrons excited into the conduction band or (ii) by "positive holes" or electron vacancies in the full band. In general, impurities produce holes or electrons more readily than excitation across the band and determine the type of conduction that predominates. When electrons predominate we have an n-type semiconductor; when holes predominate we have a p-type. A perfectly pure element semiconductor will have equal numbers of holes and electrons and the conductivity is then said to be "intrinsic." One of the great technological achievements in the purification of germanium is that samples intrinsic at room temperature are now a commonplace. This involves a purity of better than 1 part in 1000 million—particularly with respect to certain substances that readily produce free holes or electrons.

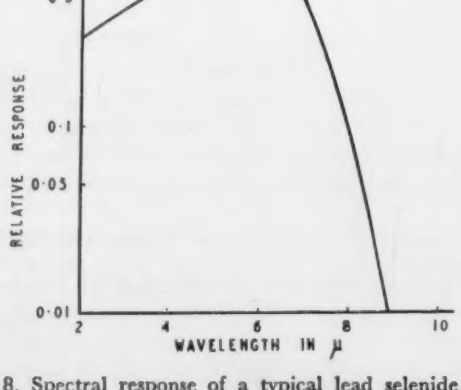

Fig. 8. Spectral response of a typical lead selenide cell at 90°K.

Here we must note a very great difference between a compound semiconductor such as lead sulfide and an element semiconductor such as germanium. Suppose we have no other constituents in the crystal but lead and sulfur. We may still not have an intrinsic semiconductor in the sense stated previously. The reason is that excess lead atoms are found to act like donor impurities and to require so little energy to release an electron that each produces a free electron in the conduction band. Similarly, each excess sulfur atom creates a hole. In addition, lattice vacancies created by excess of one constituent complicate the situation. To have nearly intrinsic lead sulfide, with no impurities added, we must also therefore have a deviation from the stoichiometric composition that is very small indeed —about 1 part in 1 million, as it turns out. Compounds such as lead sulfide can exist with relatively large departures from stoichiometric composition; this complicates the problem of obtaining an intrinsic sample considerably. We not only have to remove the impurities, but we have to get the lead-to-sulfur ratio just right! Therefore, it is not surprising that the study of these substances has been far from straightforward.

It is now more than 10 years since the group of substances lead sufide, lead telluride, and lead selenide were shown to be semiconductors (*23*) that can exist either as n-type or p-type, and to have forbidden energy gaps probably of the order of a few tenths of an electron volt. They also appeared to exist as "semimetals"—that is, substances showing metallic behavior but with lower conductivity. This is now known to take place only when they are very impure or deviate considerably from stoichiometric composition. The determination of the precise value of the forbidden energy gap ΔE at room temperature has turned out to be extremely difficult. Values varying from about 0.3 electron volt to just over 1 electron volt have been quoted for lead sulfide. Strangely enough, some of

the earlier estimates of near 0.3 electron volt have turned out to be more nearly accurate than later ones; however, the experimental conditions under which they were obtained could not have led to an unambiguous answer. The value of ΔE is undoubtedly the most important parameter associated with a semiconductor and we must pause at this stage to consider its relationship to photoconductivity.

Electrons can be excited into the conduction band, and so increase conductivity, in two ways. They can come from impurities or they can come from the valence or full band. Since there are far more of the latter (about 10^{22} per cubic centimeter), the second process is likely under most circumstances to be the more important. We may note that, as well as electrons, we get an equal number of holes in the full band by the second process. For a quantum of incident radiation to be able to do this, it must have energy not much less than that corresponding to the forbidden energy gap ΔE. Thus, for each substance, there will be a wavelength λ_c such that for longer wavelengths, photoconductivity, by this process, will not take place. The wavelength λ_c will be given approximately by the equation

$$\Delta E = hc/\lambda c \qquad (2)$$

The bigger ΔE the shorter the critical wavelength λ_c. Values of ΔE for some solids, together with the corresponding values of λ_c, are given in Table 1.

For diamond, which is an insulator, intrinsic photoconductivity will occur only in the ultraviolet, whereas in all the semiconductors listed, it is possible in the infrared. For germanium and silicon, it is limited to wavelengths less than 2 microns, whereas for the lead-salt photoconductors, considerably longer wavelengths can be reached. Thus, the low value of ΔE of the lead salts satisfies a necessary condition for their showing intrinsic photoconductivity well into the infrared. At least one other condition is necessary—that the carriers, either holes or electrons, should move reasonably freely through the crystal lattice, that is, that they have a fairly high mobility. This also turns out to be satisfied for these substances.

Table 1. Values of forbidden energy gap ΔE at 300°K and of λ_c.

	ΔE (ev)	λ_c (μ)
Diamond	6.0	0.2
Silicon	1.1	1.1
Germanium	0.65	1.8
Lead sulfide	0.30	4.0
Lead selenide	0.22	5.5
Lead telluride	0.26	4.6

In view of the great importance of the value of ΔE, we must now examine the various methods used for its determination.

Determination of Forbidden Energy Gap ΔE

A number of methods have been used to determine the value of the energy gap ΔE in a semiconductor. For germanium and silicon they have generally given consistent values, to within 0.1 electron volt at any rate. For the lead sulfide group of semiconductors the problem has been much more difficult. A brief discussion of the various methods, as well as some indication of the difficulties that arise, follows.

"Slope" methods. The number of carriers n_i in the conduction band of an intrinsic semiconductor at absolute temperature T may be shown to be given by an expression of the form

$$n_i = A(T)\, e^{-\Delta E/2kT}, \qquad (3)$$

where $A(T)$ is a slowly varying function of the temperature and k is Boltzmann's constant. If the carrier mobility does not vary rapidly with T, the conductivity σ will vary also as in Eq. 3. By plotting log σ against $1/T$, we should be able, in principle, to determine ΔE from the slope, provided that we neglect the variation of $A(T)$. Again, it may be shown that the Hall constant R— that is, the constant determining the magnitude of the transverse voltage produced by a magnetic field—varies also as Eq. 3. In this case the quantity $A(T)$ may be determined theoretically apart from a constant. By plotting log $[R/A(T)]$ against $1/T$, ΔE may also be found from the slope. This method works well only provided that ΔE is a constant or is a linear function of T. If this is true, it gives the value of ΔE *at the absolute zero of temperature*; the rate of change of ΔE with T must be known in order to determine ΔE at any other temperature. This method has worked very well for germanium and silicon. This has been so for two chief reasons. Good single-crystal specimens have been available that are sufficiently pure to obtain intrinsic conductivity at reasonably low temperatures; in addition, ΔE is approximately a linear function of T.

For the lead sulfide group of semiconductors, early work using this method gave values of ΔE varying between zero and about 1 electron volt, but frequently around 0.3 electron volt. The wide variation was the result of two main causes. The samples were too impure to show true intrinsic conductivity and they were usually polycrystalline. Intercrystalline barriers affect the variation of σ with T and may give quite misleading results. After the introduction of photoconductive cells, much work was done using evaporated layers; here again very mis-

leading results may be obtained (*23*). Therefore, when Lawson (*31*) succeeded in growing in our laboratory synthetic single crystals of all three members of the group, it was thought that much more reliable values of ΔE would be obtained from conductivity and Hall constant measurements. "Intrinsic" conductivity was found at fairly high temperatures, in the sense that the same value was found for all samples measured. At lower temperatures, where "impurity" conduction predominates, wide variations were found, as is usual. Using such conductivity measurements and also Hall constant measurements and applying the slope method, Putley (*32*) found the following values for ΔE: lead sulfide, 1.17 electron volts; lead selenide, 0.5 electron volt; lead telluride, 0.63 electron volt. These values are now known to be much too high. This has shown up the danger of using slope methods when there is no clear indication that they are applicable. Some of the reasons why the slope methods give the wrong answers have recently been discussed (*33*). They are mainly associated with the fact that $A(T)$ is not really constant and that for these substances ΔE is not a linear function of T. When ΔE is larger, these do not matter much, but for small values of ΔE, which we are dealing with in this case, they may render the slope method inapplicable. The situation is complicated by irreversible effects that take place at high temperatures owing to the changing composition of the crystals.

These irreversible effects have recently been strikingly demonstrated by Scanlon and Brebrick (*34*), who have made use of such changes to obtain lead sulfide crystals in a form showing intrinsic conduction at temperatures below 250°C. This they do by bringing natural crystals of galena into a state of equilibrium with sulfur vapor at an elevated temperature and then cooling them rapidly so that their chemical composition is "frozen." By varying the sulfur pressure, they can produce either n-type or p-type samples. By careful adjustment of the sulfur vapor pressure, a balance between donors and acceptors may be struck so that nearly intrinsic material is produced. By this method, and working at temperatures below 250°C, they have obtained a value of ΔE for lead sulfide of 0.37 electron volt by use of the slope method applied to Hall constant measurements. This is much lower than Putley's value (1.17 electron volts) and is much nearer the value that we now believe to be correct at room temperature, namely about 0.3 electron volt. The slope methods are very simple to use, but in view of the difficulties in interpretation and the rather strict requirements for their validity, it is necessary to have other methods available.

Absolute Hall constant and conductivity measurements. Instead of using the slope of Hall constant and conductivity curves, one may use the actual values to determine ΔE. This, however, involves a knowledge of the quantity $A(T)$, as defined in Eq. 3, and this in turn depends on theory and also on a knowledge of the "effective masses" of holes and electrons in the full and conduction bands. These are now known to differ considerably from the free electron mass. Unless they are known by other means, we cannot deduce ΔE. The whole point of the slope method is to avoid a knowledge of these values.

Photoconductivity. The deduction of the value of ΔE from the long-wave limit of photoconductivity using the relationship given in Eq. 2 involves the assumption that the photoconductive process is initiated by the excitation of electrons directly from the full to the conduction band. Although this is now thought to be true for all three substances of this group, other examples of photoconductivity are known in which electrons are first raised to excited bound states and then released into the conduction band by thermal agitation, or else excited from impurity centers. To show that this is not true for these substances has been a long process involving the fitting together of several pieces of the puzzle. The main evidence, however, has come from the close correlation between photoconductivity and optical absorption which is discussed in a subsequent paragraph. However, if we assume that the photoconductivity is indeed initiated by excitation of an electron right across the forbidden band, we may estimate the value of ΔE by observing the wavelengths at which the photoconductivity begins to fall off rapidly. Unfortunately, we obtain only an upper limit to the value of ΔE by this means, for the photoconductivity falls off steadily and the observed limit is set by the sensitivity of the equipment used. By this means we may show that, at 300°K, for lead sulfide, $\Delta E < 0.35$ electron volt; for lead selenide, $\Delta E < 0.25$ electron volt; and for lead telluride, $\Delta E < 0.3$ electron volt. This result was very difficult to reconcile with Putley's values obtained by the slope method and the assumption of a transition across the full extent of the forbidden energy gap, and it formed one of the chief puzzles set by this group of substances (*23*). It has now been resolved by realizing that Putley's values are much too high and that the slope methods by which they were obtained are unreliable.

Optical absorption. If the photoconductivity in the lead sulfide group is initiated by a transition across the full band, we should expect to find an increase in optical absorption as the wavelength is

decreased below the critical value given by Eq. 2. The absorption in the visible and near infrared in these substances is very high, corresponding to an absorption coefficient of the order of 10^6 per centimeter. The first experiments on variation of absorption with wavelength were therefore carried out on thin films of the substances as used in photoconductive cells. It was found that there is a rapid fall in absorption at wavelengths near 1 micron for all three substances, which corresponds to values of ΔE not very different from Putley's values. This added weight to the idea that they were correct even though it raised the difficulty associated with the long-wave limit of photoconductivity already discussed. When good single crystals were examined—both synthetic crystals of all three substances as grown by Lawson (*31*) and natural galena crystals—another absorption edge was found in each case at a much longer wavelength, corresponding very closely with the known photoconductive limit for lead sulfide and lead telluride and changing with temperature in the same way. There was therefore little doubt that it was this "edge" and not the one near 1 micron that should correspond to a transition across the forbidden gap. At first, lead selenide appeared to be an exception, for the second absorption "edge" came to a considerably longer wavelength than what was then thought to be the long-wave limit of photoconductivity. The latter, however, turned out to be wrong, and it was soon shown that the photoconductive limit and absorption edge agreed and indeed occurred at a considerably *longer* wavelength for lead selenide than it did for lead telluride, even though it might have been expected to lie between that for lead sulfide and that for lead telluride. The effect of this discovery on photoconductive cell development is discussed in the section on lead selenide cells.

A consideration of the magnitude to which the absorption increases to the short-wave side of the second edge ($\sim 10^4$ per centimeter) appeared to rule out an "impurity" process. This was also indicated by the absence of appreciable variation with impurity content as measured by conductivity. Transitions to excited states were ruled out by the fact that the associated photoconductivity still exists at very low temperatures. It was therefore concluded that this absorption does indeed correspond to a transition across the forbidden energy gap and thus we have a *direct* method of observing ΔE.

To obtain an upper limit of ΔE is again easy and indeed it turns out that the limit can be pushed to longer wavelengths than for the associated photoconductivity because the absorption can be observed for values so small that photoconductivity is inappreciable. To obtain the exact value of ΔE, some method of extrapolating the absorption curves must be used. Such a method will depend on the theory of optical transitions in solids.

Table 2. Extrapolated optical values of ΔE for lead salts.

Temperature (°K)	Lead sulfide (ev)	Lead selenide (ev)	Lead telluride (ev)
90	0.24	0.17	0.21
300	0.30	0.22	0.26
500	0.34	0.26	0.30

In order to make sense of the experimental data, one has to assume that transitions which are "forbidden" by selection rules to the first order can indeed take place. This involves exchange of energy and momentum with the crystal lattice during the transition. Such transitions were at one time thought to be very improbable, but it has recently been shown by several theoreticians that this is by no means correct. G. G. Macfarlane (*35*) has applied the theory of such transitions to germanium and silicon and has found excellent agreement with recent very accurate measurements of the absorption in these substances by V. Roberts (*35*). By this mean, very accurate values of ΔE have been obtained that are consistent with those obtained by other means. This technique may also be applied to the lead sulfide group. The most complete absorption data on all three substances is that of Gibson (*36*). By using this, with certain corrections for variation of dispersion, the values of ΔE given in Table 2 (called "extrapolated optical" values of ΔE) are found (*33*). This method seems to be so accurate that it would be worth obtaining even more accurate absorption data, with higher resolution.

I should perhaps point out that the values for ΔE given in Table 2 will not correspond in practice to the observed long-wave limits of photoconductivity with thin layers. At some shorter wavelength the absorption will have become too small to produce enough photoelectrons to observe. In addition, with thin layers the corresponding second absorption edges are frequently obscured by scattering from the microcrystalline structure of the layer. They have, however, now also been observed using evaporated thin layers.

Determination of Other Parameters

If we accept the value of ΔE given by the measurement of optical absorption, it can then be used to obtain other important quantities. Used in conjunction with an analysis of Hall constant and con-

ductivity data, values of the effective masses of holes m_h and of electrons m_e may be found, or at least the quantity $(m_e\ m_h/m^2)^{\frac{1}{3}}$. The value appears to be between about 0.15 and 0.25 (*33*). Recent measurements by Bloem, Kröger and Vink (*37*), at the Phillips Research Laboratory, Netherlands, based on thermoelectric power give

$$m_e = m_p = 0.25\ m.$$

Using these values, a value of ΔE has been determined (*37*) from measurements of the resistance of the junction between a p-type and n-type crystal and a value 0.3 ev has been found; this is in agreement with the optical value.

The value of the electron mobility μ_e and hole mobility μ_h may be deduced from conductivity and Hall constant measurements. For all three substances of the group, over a wide range of temperatures, extending from 100° to 800°K, the electron mobility for an n-type crystal may be represented by an expression of the form $AT^{-5/2}$, where A is a constant. The value of A varies somewhat from one specimen to another and there appears to be no precise correlation with impurity content as there is for germanium. Values of the hole mobility are more difficult to obtain at the higher temperatures owing to difficulties associated with the reversal of the sign of the Hall coefficient for p-type samples. At temperatures below about 300°K, a similar expression holds for the hole mobility; for higher temperatures the hole mobility appears to decrease more rapidly than the electron mobility. Some approximate values of the electron mobility at 300°K are shown in Table 3. These are average values derived from measurements of a number of single crystals by E. H. Putley and there is considerable variation between individual samples. They should therefore be regarded only as approximate values. They are not so high as the values for germanium, but they are still reasonably high values; therefore, a second requirement for a substance to show marked photoconductivity as indicated in the section on the lead sulfide group of semiconductors is satisfied by all three members of the group, but especially by lead telluride.

One other very important quantity that affects the practical use of any semiconductor is the lifetime of carriers that are created in excess of the equilibrium numbers, for example by radiation. Many of the remarkable developments of devices using germanium owe their operation to the fact that lifetimes of the order of 100 microseconds or more are obtainable with good single crystals. For the lead sulfide group of semiconductors, lifetimes of this order have never been observed in single crystals. Moss has measured lifetimes varying between about 10^{-4} and 8 microseconds (*38*). For photoconductive layers, however, apparent lifetimes up to about 1000 microseconds have been observed. These can hardly be a property of the pure crystalline material but are more likely to be a peculiar property of the layer that results from the trapping of carriers near the surfaces of the microcrystals of which the layer is formed.

Table 3. Electron mobility (μ_e) of lead salts at a temperature of 300°K.

Salt	μ_e (cm²/volt sec)
Lead sulfide	550
Lead selenide	900
Lead telluride	1600

Physical Chemistry of Lead Sulfide

A study has recently been made of the physical chemistry of lead sulfide by Bloem, Kröger and Vink (*37*). In particular, the equilibrium of lead sulfide at elevated temperatures with S_2 vapor has been studied in some detail. The S_2 partial pressure was varied by varying the concentrations of hydrogen and hydrogen sulfide in equilibrium with the sample. When equilibrium had been established, the sample was cooled rapidly and the carrier density was determined by Hall constant measurements. In this way the S_2 vapor pressure required for the change from n-type to p-type has been determined as a function of the temperature, both for pure lead sulfide and for samples doped with controlled amounts of impurity in the form of silver and bismuth. Semiconductors of this form differ from germanium in that in general such doping does not give a number of free carriers equal to the number of impurity atoms incorporated, even though the energy required to release a carrier is very small. The carriers that would otherwise be free may be captured by ion vacancies in the lattice owing to deviations from perfect stoichiometric composition. It is found, however, that for impurity concentrations of bismuth and silver of the order of 10^{18} per cubic centimeter over a limited range of sulfur pressures, one does indeed obtain an equivalent number of free carriers—the so-called "controlled valency" range; otherwise the number of free carriers obtained depends on the partial pressure of S_2 under which the sample is brought into equilibrium. The inclusion of silver and bismuth impurities also has the effect of changing the value of the S_2 partial pressure required at any given temperature for the transition from n-type to p-type.

One very important parameter determined as a result of this work is the reaction constant giving the

product of the number of Pb^{++} vacancies and the number of S^{--} vacancies in equilibrium. It was also found that the energy ΔE gap tends to a value of 0.5 electron volt at temperatures above 1000°K. This value depends on the assumption that the effective masses of holes and electrons are $0.25m$ as determined by experiments on the thermoelectric power of the same crystals as used in these experiments.

Band Structure of Lead Sulfide

So far, an extensive theoretical calculation, using quantum mechanics, of the form of the energy bands has been carried out only for one of the members of this group of substances, lead sulfide. The resulting band structure agrees surprisingly well with the picture we now have built up from the experimental data. These calculations, carried out by a theoretical group in our laboratory (*39*) show that both the conduction and full band are complex. We give, however, a simplified diagram in Fig. 9. Here are shown only two of the energy curves—the two that approach most closely and so define the forbidden energy gap. These curves apply to the (1,1,0) direction in the lead sulfide crystal and show the energy as a function of the momentum vector P expressed in terms of the lattice constant defining a unit cell in the crystal. The most interesting feature of these curves is that the smallest energy separation occurs for quite different values of P and a transition from the highest point in the full band to the lowest point in the conduction band requires a large change in P—that is, in momentum. Such transitions are optically "forbidden" to a first order but are now known to occur with appreciable probability. The long-wave limit of absorption owing to electronic transitions from the full band to the conduction band therefore corresponds to a transition of this kind (transition A in Fig. 9). The theoretical value for the energy change of 0.3 electron volt is in excellent agreement with the experimental value. The lowest energy for a direct transition involving no transfer of momentum to the lattice appears to be about 1.3 electron volts. This corresponds to a "vertical" transition (transition B in Fig. 9). The forbidden energy gap as measured by "thermal" experiments such as variation of conductivity with temperature, should of course give the smallest value of the energy separation, that is, one corresponding to transition A.

Physics of Photoconductive Cells

Although considerable advances have been made in our knowledge of the fundamental properties of the substances of which the sensitive layers of lead salt photoconductive cells are made, the detailed

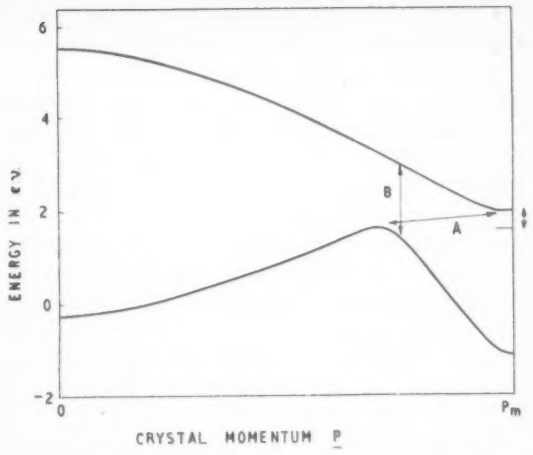

Fig. 9. Simplified diagram of the band structure of lead sulfide.

mechanism of the very marked photoconductivity that they exhibit is still far from being fully understood. This is not surprising since the thin sensitive layers consist of aggregates of tiny crystals ranging in size from about 1 to 0.01 micron. The contacts between such crystals are likely to play a large part in determining the resistance of the layer. There is indeed a great deal of experimental evidence that this is so. These contacts are also likely to affect the photosensitivity, although there is no general agreement on the part they play. Some hold that they determine almost entirely the photoconductive properties of the layer, while others have supposed that they may be ignored. If it is assumed that the layer behaves like a homogeneous thin sample of lead sulfide, then it must be very nearly intrinsic throughout to account for its high resistivity. This is extremely unlikely in view of the difficulty in striking an exact balance between p-type and n-type impurities (one would scarcely suggest that there are no impurities present). On this view, sensitization with oxygen would be a process for achieving this balance, for oxygen is known to render these substances more like the p-type. Although the treatment is fairly critical, it is hardly critical to the extent that would be required for such a balance. A much more serious difficulty would be to account for the very long lifetimes observed in sensitized photoconductive layers. It is well known from experience with germanium that such long lifetimes do not occur in "balanced impurity" specimens, but only in good single crystals that are fairly pure.

It is more reasonable to assume that the layers consist, as is known from electron microscope photographs, of small crystals, and to consider the effect of oxygen treatment on these. One theory that has been developed by several authors assumes

that, owing to the different sizes of the crystals and other uncertainties, some are converted from n-type to p-type during oxygen treatment and some remain n-type. We thus have a series of p–n junctions throughout the layer. The properties of such junctions are now well known from transistor studies. They act as rectifying contacts and have a high back resistance. We thus have at once an explanation of the high resistance of the layer. Moreover, in such a junction, current in the high resistance direction is carried mainly by the minority carriers. Thus the number of effective carriers may be greatly reduced. Incident radiation would therefore have a relatively much greater effect in reducing the resistance.

At this point theories diverge again. Some regard the resistance change as caused by a modulation by the radiation of the heights of the intercrystalline potential barriers set up by the p–n junctions; others consider it as a bulk effect in a medium whose composition varies from n-type to p-type irregularly. In the small crystals with which we are concerned, these divisions are hardly significant. There is very little doubt that photoelectrons are produced throughout the bulk of the crystals—and indeed a change in minority carrier concentration will affect both the conductivity of the bulk part of a p–n junction and the effective height of the potential barrier.

It is, however, in my opinion, not necessary to assume such a random distribution of p-type and n-type crystals. The effect of the oxygen treatment may be to create a p-type layer on the surface of each small crystal. This process would be much less critical, since it does not require an exact balance of impurities. The p–n junctions would then be internal. The effect of such a p-type layer would be to suck many of the free electrons from a small n-type crystal and to store them in a space charge layer near the surface. This would not only set up a barrier but would decrease the bulk conductivity of the crystal. This decrease would only be appreciable for small crystals, such as we have in these layers, since the "exhaustion region"—that is, the region depleted of electrons—extends only a short distance from the junction. Such a process would explain all the effects which any of the other models seek to explain and seems simpler to accomplish. I have discussed the various theories more fully in the review already referred to (*23*).

One great difficulty still remains and it seems pointless to try to decide among the various theories, all of which probably are partially true, until this is clarified. The difficulty concerns the very long lifetimes observed in sensitized layers, as compared with single crystals. It is indeed upon these long lifetimes that the high sensitivity of the layers largely depends. The increase in carrier density over the thermal equilibrium value, produced by a small flux of radiation, is proportional to the lifetime, since, in steady conditions, a balance must be struck between rate of production and the rate of decay. The latter is proportional to the product of the increase in minority carrier density and the reciprocal of the lifetime, and the former is constant. One thing seems to be clear: some of the carriers produced by the radiation must be caught in some form of "safe" trap in which they are screened from recombination. If the bulk of the crystal is n-type, it is the holes formed by the radiation that must be protected. One possibility is that many of the photoelectrons become caught in deep traps in the p-type surface layer from which they diffuse slowly back into the n-type material after removal of the exciting radiation. Until there is some direct experimental evidence concerning the actual process taking place, there seems little point in further speculation. We have here an example of a physical process, not fully understood, being used practically to great advantage; in this case the empirical approach has beaten the fundamental one. There is very little doubt, however, that a more precise control of sensitivity will be achieved when the photoconductive process in layers is fully understood.

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Benjamin Franklin and Communication

Despite all the proud titles he won in a lifetime of service to humanity, Franklin described himself in his last will and testament—"I, Benjamin Franklin, Printer. . . ."

He knew that printing, advertising, and the graphic arts offered the means for communicating the ideas that could reshape the world. His theory of the "electric fluid" helped to pave the way for the later great media of communications—the telephone, telegraph, radio, and television.

"When men differ in opinion," Poor Richard wrote in his *Apology for Printers*, "both sides ought equally to have the advantage of being heard by the public; and when truth and error have fair play, the former is always an overmatch for the latter."

Some Merits and Misinterpretations of Scientific Method

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A PHILOSOPHIC appraisal of science seems to me to involve four main areas: (i) the methodology of the sciences; (ii) the synthetic view of nature that results from the results achieved in the sciences, that is, the formation of a cosmology; (iii) the value commitments of science; and (iv) the impact of science on civilization. This article discusses some merits and common and pernicious misinterpretations of the methodology of the sciences.

What is scientific method? Philosophers and scientists have written tome after tome in answer to this question, and the discussion rages yet today. The philosophy of science has been mainly a philosophy of scientific method. The journals are filled with articles propounding or interpreting Galileo's method; Descartes' *Discourse on Method;* Newton's famous statement, "I make no hypotheses"; Ernst Mach and logical positivism; and John Dewey's instrumentalism—to mention only a few topics. Each of these views needs analysis, but underlying them all is an ambiguity from which much of the disagreement stems. This is an ambiguity in the phrase *scientific method*. The ambiguity is seen in the following questions: By what method was the law discovered? By what method is the law justified (proved)?

Scientific method sometimes refers to the art of discovery and at other times to the rigorous procedure of verification (justification). Failure to distinguish this ambiguity has led to endless debate concerning whether or not "scientific method" can be formulated in a series of definite, related steps that any intelligent person could apply. To those who propound such explicit procedures, the stock-in-trade reply is "why don't you go into the laboratory and discover a new law?" Most everyone knows that most everyone cannot meet the challenge.

What can we say about the art of scientific discovery? First, so far as we know now, it has not been formulated in any set of procedures. It seems to be a private psychological affair such that when it is characterized by those who possess this art, very different descriptions are presented. They talk of intuition, insight, creative imagination, myths, religion, mysticism, inspiration, and so forth. They refer to hints, models, analogies, metaphysics, "fiddling," "guessing," and "hunches." Most of the processes referred to by these terms are not describable. A few, like analogies and models, can be described and are sometimes helpful as hints to beginners. Mill's methods of inductive discovery are the most successful formulation of one kind of approach. Einstein in particular has emphasized the role of creative imagination, the free play of ideas.

Quite opposite is the nature of scientific justification. Various labels have been applied to several distinct procedures: observation and generalization, experimentation, scientific proof, verification, confirmation, induction, and hypothetical deduction. The basic aim of these procedures is to produce an explicit set of rules such that any qualified scientist can check the results claimed in some discovery. This is the heart of science's claim to objectivity. The relevant facts must be defined in terms of operational definitions, and the theoretical entities must be explicitly connected to them by mathematical-logical relationships. An operational definition states a rule that relates some term to some publicly observable processes, objects, or events. Such definitions guarantee the objectivity of terms for any scientific observer. Since the theoretical entities are connected by explicit mathematical-logical relationships to operationally defined entities, they have a particular kind of publicity or objectivity for science. It is crucial for a precise comprehension of the status of scientific entities not to confuse the publicity (objectivity) of operationally defined entities with that of theoretical entities.

Thus scientific justification gives us a publicly tested and testable fund of knowledge clearly and distinctly formulated in scientific treatises and articles. Scientific justification is the necessary

check on the flights of scientific discovery, and scientific discovery is the means for adding new knowledge to the fund publicly justified. The obvious and tremendously important merit of scientific justification is that it enables us to settle disagreements about matters of fact; to reach agreements acceptable to all. If only scientific justification could be extended to social, political, ethical, and religious disagreements. I shall return to this point shortly. Nor should we forget the value attached to the artistic creativity involved in scientific discovery. Such creativity in some form is, I think, a very important psychological state for a satisfactory life.

The distinction between scientific discovery and scientific justification explodes the ambiguity in the term *scientific method*. I intend in the rest of this article to use the term *scientific method* to denote the combination of these two procedures. The combined whole, scientific method, has some very important characteristics relevant to our topic. Neglecting important details, the whole procedure is briefly as follows. (i) The activity of scientific discovery under conscious direction or as a result of some surprising peripheral accidents turns up a new conjecture that has explanatory possibilities. (ii) This conjecture under analysis yields a critical reformulation called a hypothesis. (iii) The hypothesis necessarily implies certain definite consequences, some of which can be experimentally checked. (iv) The hypothesis, plus consequences, provides a representation and/or explanation of empirical data already known and in some cases predictions about unrelated data. (v) The conformity of such consequences is checked with the best reliable evidence available at that time.

Now this general procedure exemplifies a basic logical pattern as follows. (i) If the hypothesis is assumed to be true, then certain consequences can be expected to result. (ii) The resultant consequences are in conformity with the relevant empirical data or not. (iii) If there is conformity between consequences and data, then the hypothesis may be an explanation. (iv) If there is not conformity between consequences and data, then the hypothesis has one strike against it. Notice that in this last step I do not say the hypothesis is negated because there are in the history of science very few, if any, so-called "crucial" experiments. A logical analysis of this point is easy to make, but I omit it here. [P. Duhem, *The Aim and Structure of Physical Theory* (Princeton Univ. Press, Princeton, N.J., 1954), pt. 11, chap. VI.]

The afore-mentioned steps can be thrown into the logical form: if H then C; C is true (conforms); or C is false (disconforms). Now logic proves that if C is true, we cannot assert the truth of H because some other hypothesis might also have the same consequences. Logicians call this the fallacy of affirming the consequence. What this means for us is that no matter how successful the continued conformity between consequences and data, the truth of the hypothesis cannot become a certainty. It remains a probability, albeit in some cases, a very high one.

This fact about the nature of what I am calling scientific method has been subject to much misinterpretation, and I must clear away this rubbish before I state its proper merits and limitations. The first misinterpretation is the claim that "science can never hope to reach the truth." Since science cannot reach the truth, then its results are not of cognitive importance; they tell us nothing about reality. And if science cannot reach the truth, we will have to turn to something else that can. The usual twist at this point is that something like religion can break through to the truth. The variations played on this theme are legion. The fallacious assumptions underlying this misinterpretation are (i) that something called "certain truth about reality" lies around the corner, and (ii) that any cognitive enterprise that deserves the name will contain a method capable of "latching on" to this truth. But I am at a loss to understand the reasons for either assumption in a way that does not beg the question at issue. Such is the misinterpretation coming from the absolutist, whatever be his breed.

The converse misinterpretation comes from the skeptic to the effect that if science does not give us the truth with its careful critical formulation and experimentation, then nothing can. It is merely an instrument to power, an amusing pastime whose results are arbitrary and even sometimes conflicting. The stock-in-trade illustrations are the so-called "paradoxes" in Newtonian physics concerning the additive character of velocities pointed out by Einstein and the old wave-particle conundrum in quantum physics. But these are paradoxes only to those who will not trouble to think through the problems they pose. The skeptic says "science frustrates itself in its search for knowledge because it leads to contradictions. The search is a fake."

The curious thing to me is that the skeptic and the absolutist share the same assumptions from which their converse misinterpretations follow. Each finds a gap between the results of scientific knowledge and certain truth. The absolutist must bridge the gap by some leap of faith, and the skeptic makes an idol of his ignorance of certainty. Is there not a middle ground concerning scientific knowledge?

Both of these misinterpretations rest on false as-

sumptions. What reasons do we have for assuming what is called certain truth about matters of fact? Do we have a single example with sufficient evidence? Why must knowledge be certain in order to be called knowledge? Let us simply state what we have in scientific knowledge. It is reliable information relevant to a context of data. It enables us to understand and predict. It is subject to change. It cannot lay claims to absolute truth, since other hypotheses are always possible. Against the skeptics, it provides us with accurate knowledge about matters of fact—knowledge that is tested in a public market place open to all interested parties, knowledge that can settle issues of dispute. Against the absolutists, its logic explodes any claims to infallibility—claims that too often in man's history have led to intolerance and totalitarianism, political, religious, and social. These are its merits, and I confess that I do not see how these can be construed as limitations. You cannot ask it to do what by its very nature it cannot achieve; that is the height of foolishness; and if your limitations are based on such inabilities, they are not limitations at all.

In order to guard against a misunderstanding of my remark that scientific method has no limitations, let me explore another frequent misinterpretation. There are those who, seeing what science purports to do and that no intrinsic limitations are involved in its ability to achieve these ends, rush headlong into the worship of science. The worship of science is often called scientism or science-as-the-sacred-cow. It has now become the final authority on all matters, and what its practitioners (the scientists) preach is taken as the gospel. "Should we repeal the fifth amendment?—go ask the scientists—they know." When science becomes scientism it is just as dangerous an authoritarian as those other species, political and religious, we know so well.

Related to these misinterpretations of scientific method is another that is growing in contemporary circles. It revolves around the distinction in physics between mechanical and mathematical explanations. The ideal of Newtonian physics was to find a mechanical explanation for events. At first this meant a visual model of discrete entities in motion whose position, mass, and velocity at a time enabled one to give a complete description of its past and future physical states. This description had to be modified later on to take care of other phenomena; hence, visual wave models were also introduced. But modern physics has found both of these models inadequate, and we seem compelled to give up a demand for visual models and allow mathematical models. In the mathematical models we can "feed" some data into the equations and derive some predicted results.

This situation has led some physicists to say that we no longer know what nature is really like; all we can do is juggle some data through equations and come out with the answer. The history of physics is characterized as a progressive departure from knowledge of how nature really behaves. I call this view "pessimistic physics," and I think it has misinterpreted the character of physical knowledge. The misinterpretation rests on the assumptions that (i) there exists an external nature or reality to be known by science, and (ii) that the success or failure of science is to be measured by the degree to which it gives us knowledge about external nature or reality. But the slip in this view is how do we measure the degree to which science gives us knowledge of reality or nature as it really is? It implies that there is some other source of knowledge about reality outside of science by means of which we should be able to make the required comparison. What is this source and can it withstand philosophic criticism?

On the contrary, we need take no such pessimistic view. The foregoing assumptions are questionable, and, in fact, I see little evidence for them. Those dualistic philosophies that separate our scientific knowledge of events from some underlying reality are continually frustrated by the problem of how the two are related. Knowledge about reality in such views always comes back to some kind of leap of faith outside of reliable scientific knowledge that is untestable in the public market place of knowledge. Nature simply is, at any given time in the history of science, the reliable information obtained by the scientific enterprise. If reliable information in modern physics depends on using mathematical, rather than mechanical, models, then physical nature is the description of states found therein. Our understanding need not be shocked by the changing character of nature unless some yearning for the absolute unchanging reality holds us. I see no reasons why it should.

The misinterpretation that leads to pessimistic physics has its converse fallacy. This is the reification of abstractions or what Whitehead calls the fallacy of misplaced concreteness or Dewey's fallacy of selective emphasis. Persons who fall into this trap agree with us in rejecting the notion of a reality behind scientifically observed events, but they take the description of nature given by science at some stage that utilizes certain abstract concepts and postulate this selected emphasis as the way nature really is. They take the abstractions convenient at one stage of science to be the real unchanging objects of nature. There is nothing in sci-

entific method itself that would warrant taking either of these extremes.

I now turn to a second pair of ambiguous meanings in the phrase *scientific method* that has been the source of much confusion. On the one hand, there is a strong tendency to identify scientific method with the highly sophisticated form it has achieved in mathematical physics on the assumption that physics is the most advanced, successful, and objective of the sciences. Persons holding this view aim at making every science like physics in its methodological character. Some contemporary psychologists have been seduced by the success of physics. Briefly, scientific justification on this view is a particular pattern of relationships among hypotheses, deductions, and experimental verification. Let us call this the "narrow view." In contrast to it there is a broader meaning of scientific method. In this sense, it is not identified with any particular form but rather with the critical spirit of all scientific thinking. Whatever the particular method, it aims at achieving certain common goals: namely, a critical and skeptical spirit toward accepted results, publicity and objectivity of claims, and willingness to follow evidence and logic wherever it leads. These aims are likely to be accomplished by various methods relevant to various subject matters. Let us call this the "broad view."

In terms of this distinction between broad and narrow scientific method we can settle another misinterpretation. There is the old argument concerning whether the social sciences are sciences. Now, there are various reasons why some persons wish to claim that the social sciences are not sciences: (i) some fear that they will invade and make public the hidden, private side of life; (ii) some fear that they will destroy certain moral sentiments, beliefs, and deeply rooted principles (prejudices); (iii) some fear the loss of the freedom of the will; and (iv) some identify science with physics, believe it or not. All of these reasons stem from two sources: (i) the confusion of the broad and narrow views; and (ii) the rejection of the afore-mentioned aims of scientific method.

But there is no reason why the social sciences should "hamstring" themselves with the method of physics. No evidence has been presented to show intrinsic reasons why they cannot seek and progressively attain the goals of scientific method in the broad sense, although the path be slow and long. To deny this is to limit scientific method to the narrow sense. On the other hand, to reject the social sciences as sciences because one rejects the goals of scientific method in the broad sense begs the question, for it rejects science *in toto*. Such a rejection cannot be argued on pain of contradicting oneself. Thus I can seen no inherent limitation on what subject matters can be treated scientifically in the broad sense, and I consider this lack of limitation a distinct merit of scientific method.

But some may wonder whether I mean this conclusion to apply to such subjects as history, philosophy, and religion. I confess that I do, and now I must make out my defense. In the light of the goals I stated for scientific method in the broad sense—the critical attitude, objectivity, evidence, and logic—I see no reason why these are not the goals of investigation in history, philosophy, and religion. The particular methods worked out to achieve these goals will probably vary, but surely the historian and philosopher demand (i) that their results be taken with a grain of doubt, (ii) that other historians and philosophers can arrive at the same conclusions, given the same evidence and rules of procedure, and (iii) that they follow that evidence and logic wherever it leads. There is some discussion these days on whether these are the goals of religious study. If religions do claim factual or moral truths, I do not see how they can avoid these goals. If religions claim some other goals, they need to be made clear.

In closing these remarks on scientific method, I wish to discuss two important value commitments ingredient in it. First, the goals of scientific method are incompatible with dogmatism, because the logic of scientific method is such that a hypothesis cannot be claimed as a certainty. By dogmatism I mean (i) the adherence to a belief as absolutely certain, or (ii) the acceptance of a belief as true without sufficient evidence, or (iii) the adherence to a belief in the face of refutatory evidence. The possession of an undogmatic mind, that is, a tolerant mind, seems to me a central value for civilization. It is an ideal few possess. Not many scientists possess it generally but only within some limited field that is their speciality. It is a value, the worth of which has been continuously manifest in the genuine practice of scientific method. Tolerance seems to me one of the central values to the thesis that man alone is sufficient to solve his problems. Lack of tolerance is what continually wrecks the human solutions of man's problems.

The second value ingredient in scientific method is objectivity. By objectivity I mean the specification of procedures for evaluating relevant data such that conformity to these specifications yields agreement among inquirers. I do not mean by objectivity what has sometimes been expressed as finding out how things really are, independent of observers. The latter is a false quest for two

reasons: (i) we cannot get rid of the observer; and (ii) we have no direct access to reality by means of which to check the degree of objectivity obtained. The tentative agreement brought about by objectivity is a necessary part of public knowledge that is undogmatic in its claims. Without objectivity the value of tolerance would collapse into the most anarchistic relativism, because there would be no means for resolving disagreements. The value of objectivity to the quest for knowledge is thus manifest. I consider it a distinct merit of scientific method to bring out the basic values of tolerance and objectivity for the solution of man's various problems.

Benjamin Franklin and Science

In recognition of the 250th anniversary of the birthday of Benjamin Franklin, which occurs on 17 January, the cover this month is a reproduction of the portrait made by Thomas Sully. At the instigation of 21 of the societies and institutions with a Franklin tradition, this anniversary is being widely celebrated. There are approximately 200 societies, institutions, associations, businesses, and public service units in 12 different countries with a strong Franklin tradition.

The sciences to which Franklin made particular contributions were electricity, chemistry, physics, medicine, agriculture, botany, meteorology, navigation, aeronautics, astronomy, and geology. In a letter to Joseph Priestley written 8 February 1780, he said. ". . . The rapid progress *true* science now makes, occasions my regretting sometimes that I was born so soon. It is impossible to imagine the height to which may be carried, in a thousand years, the power of man over matter. We may perhaps learn to deprive large masses of their gravity, and give them absolute levity, for the sake of easy transport. Agriculture may diminish its labour and double its produce; all diseases may by sure means be prevented or cured, not excepting even that of old age, and our lives lengthened at pleasure even beyond the antediluvian standard. O that moral science were in a fair way of improvement, that men would cease to be wolves to one another, and that human beings would at length learn what they now improperly call humanity."

Survey of the Gothic Natural Area

HERBERT A. McCULLOUGH

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WITH the publication of "Nature Sanctuaries in the United States and Canada" (*1*), it became evident that little has been done about the description of the various nature sanctuaries, particularly those that are of value to the biologist. Niering (*2*) has suggested that "in an ecological analysis of a [natural] area, the specific problems are to: 1. Describe and map the existing vegetation. 2. Determine the successional changes or trends operative in the area. 3. Correlate vegetation- and fauna-productivity in the communities. 4. Determine the interrelationship between plants and animals. 5. Study the effects of the different intensities and modes of man's use in the area. 6. Investigate artificial methods which could be initiated to control succession if desired." Notably absent from this list is an indication of the need for knowledge of the climatic and edaphic factors. Also excluded is the consideration of geology and topography, both of which seem to be important.

The Gothic Natural Area, a virgin forest located near the Rocky Mountain Biological Laboratory, Crested Butte, Colo., is favorably situated for research. A description of this natural area seems of value and is the purpose of this article (*3*). Later studies are planned for vegetational and ecological analysis of the several different communities in the Gothic Natural Area.

The term *natural area* has several interpretations, but it is used by the U.S. Forest Service to designate a region of area less than 5000 acres that has been set aside to preserve special botanical and other biological values because the natural vegetation is virtually undisturbed. Under regulation U4 of the U.S. Department of Agriculture (*4*), authority is given to the chief of the Forest Service to "determine, define, and permanently record . . . a series to be known as natural areas sufficient in number and extent adequately to illustrate or typify virgin conditions of forest or range growth in each forest or range region, to be retained in a virgin or unmodified condition for the purpose of science, research, and education." The 1949 Yearbook of the Department of Agriculture (*5*) lists 58,236 acres in 21 states that have been set aside as natural areas. In general, these areas are controlled by the local representative of the Forest Service.

The Gothic Natural Area is administered by the district ranger with the Rocky Mountain Biological Laboratory cooperating in an advisory capacity. It is located in the Gunnison National Forest in Gunnison County, Colo., on the western slope of the Elk Mountains. It lies on a north- and northeast-facing slope of Mount Baldy (elevation 12,809 feet) and drains into the valley of the East River. The vertical range extends from about 9800 to about 12,000 feet. The area is about 2 miles from Gothic, a ghost town now occupied by the Rocky Mountain Biological Laboratory, and 10 miles by road from Crested Butte, the nearest incorporated town.

Climate

Few climatological data can be obtained directly from the Gothic Natural Area. During the winter the entire East River Valley is covered by deep snow for a 3 or 4 month period, and accessibility at other times may be difficult because of weather conditions. However, a U.S. Weather Bureau Local Observer is stationed in Crested Butte (elevation 8867 feet) and Weather Bureau records are available for this town. Comparisons were made, when possible, between climatological data for Crested Butte (*6*) and available records for the Gothic Natural Area. Other information is based on the data collected at Crested Butte.

During the summer of 1951, daily temperatures were obtained in the area at the 9800-foot level with a sheltered maximum-minimum thermometer. These records were compared with corresponding ones from Crested Butte. The minimum temperatures in the area had a mean difference of + 1.3°F from those of the town for the 34-day period; maximum temperatures in the study location had a mean difference of – 3.6°F from those of Crested Butte.

Table 1 shows the mean maximum and mini-

Table 1. Average climatological data for Crested Butte, Colo. Precipitation is averaged from data recorded during a 42-year period; temperature and snowfall are averaged from data recorded during a 40-year period.

Month	Maximum temperature (°F)	Minimum temperature (°F)	Monthly precipitation (in.)	Monthly snowfall (in.)
Jan.	29.05	−3.97	2.49	33.45
Feb.	32.59	−0.56	2.28	30.31
Mar.	38.40	6.88	2.25	29.01
Apr.	47.87	18.29	1.78	16.82
May	59.85	27.83	1.43	8.46
June	70.72	33.31	1.52	0.84
July	75.82	38.29	2.07	0.00
Aug.	74.63	36.97	2.10	0.00
Sept.	67.40	29.40	2.13	1.10
Oct.	57.21	18.53	1.30	5.54
Nov.	42.90	7.09	1.40	17.54
Dec.	31.95	3.10	2.21	28.77
Annual	52.20	17.93	22.96	171.84

mum temperatures at Crested Butte for a 40-year period. The last killing frost in spring has been reported to range from as early as 10 June to as late as 27 August; the first killing frost in the fall has been reported to range from as early as 1 August to as late as 14 September. Since 1931 the length of the frost-free period has varied from 1 day in 1950 to 86 days in 1937. The average date of the last killing frost in the spring for a 20-year period prior to 1931 was 6 July. During the same period, the average date of the first killing frost in autumn was 16 August, and the average length of the frost-free period was 41 days. The date of the last killing frost in spring is reported to be from 10 to 14 days later with each 1000-foot increase in altitude; autumnal frosts begin earlier but are more variable (*7*). It is evident from these data that the Gothic Natural Area has a short growing season with warm daytime temperatures during the summer months and low temperatures during the winter. The night temperatures are cool to cold throughout the year.

Table 1 also shows the mean monthly and annual precipitation at Crested Butte from 1910 to 1952. The precipitation is rather uniformly distributed throughout the entire year, and much of the moisture is in the form of snow. Since an increase in elevation usually brings about an increase in precipitation (*8*), the precipitation of the area should be somewhat higher than that of Crested Butte.

The mean snowfall at Crested Butte is great, as is indicated by the mean annual figure of 171.84 inches. Stories of the quantity of snow in the East River Valley at Gothic indicate that a tremendous amount is accumulated. Access is usually gained to the valley during the winter by skis. The snow remains in the woods for a considerable length of time in the spring and early summer. During the summer of 1951, a large quantity of snow was in the forest, even at the lower elevations in the area, as late as 4 July. Table 1 shows the average monthly and annual snowfall for Crested Butte over the 40-year period.

Geology

The Gothic Natural Area is underlain by Pierre shale, Tertiary porphyry, and glacial till and outwash. The Pierre is a uniform dark gray to black, thinly bedded, clay shale. Many small lenses of limestone and calcareous shale are present. These become more abundant in the lower part of the formation close to the Niobrara limestone along the northeastern border of the area. These lenses are less than 1 foot thick, but a few reach thicknesses of from 1 to 3 feet. A few marine fossils occur in the limy layers. *Inoceramus* is the most common genus, but it is accompanied by occasional ammonites and other fossils. Sandstones, which sometimes occur in the upper Pierre and also above it, are not present within the area.

The Tertiary porphyry is either a monzonite or quartz-monzonite porphyry that contains an abundance of free-weathering phenocrysts of orthoclase feldspar from 1 to 2 inches in length. Although many small dikes and sills are undoubtedly present within the forest, thick vegetation obscures the outcrops. At least three, and possibly four, closely spaced sills are well exposed. These sills are mapped as a single body of rock in the Anthracite-Crested Butte folio of the U.S. Geological Survey (*9*) and are similarly shown in the accompanying block diagram that was derived from the folio map (Fig. 1). Although it does not directly conform to

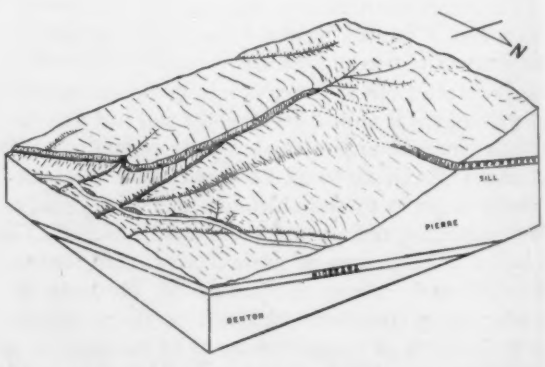

Fig. 1. Geology of the Gothic Natural Area. [Redrawn from a diagram furnished by R. L. Langenheim]

the outline of the area, the block diagram shows the important geologic features.

Bedrock within the area dips 15 to 20 degrees southwest, a feature that greatly affects the form of Quigley Creek Valley. Downstream, the valley is nearly parallel to the strike and is underlain by Pierre shale. The sills crop out along the south side of the creek, forming a wall-like cliff that protects the steep undercut slope south of the stream. The northeast wall slopes gently upward from the creek and merges with the general surface of the wall of East River Valley. The gradient of this part of Quigley Creek is steep because it is flowing down the glacially steepened wall of East River Valley. Three-fourths of the way up Quigley Creek Valley, the sills cross the creek, causing a series of prominent cascades. Upstream from the cascades the valley becomes a hanging cirque whose south and west walls are steep slopes cut in Pierre shale. The northeast wall, on the other hand, slopes gently upward from the creek on the dip slope of the porphyry until it intersects the sides of East River Valley. The floor of the cirque is a porphyry sill.

The soils of the Gothic Natural Area are derived chiefly from the Pierre shale and are black in color. In some of the upper regions, the shale is only partly disintegrated; some alpine plants are growing on this material.

Description

Observations within the Gothic Natural Area were made during the summers of 1946, 1949, and 1951. A modification of the point-quadrat method that was originated by grassland ecologists (*10*) was adopted for use in those parts of the area where herbaceous growth is predominant. A point was placed on the toe of the observer and the community was paced; the plant cover of the point was recorded for each pace. Some of the regions are so small that fewer paces than are desirable had to be employed. In the grassland region, the several isolated patches were sampled separately and the data were combined. Modifications of this method were used for the trees and shrubs in regions other than those of the mature forest. The data were converted to percentage of cover on the basis of traverses made in areas covered by vegetation. In this study, methods were employed solely to aid in the general description of the several divisions. More accurate data will be obtained in the different regions by subsequent studies.

The original Forest Service description and map of the Gothic Natural Area lists the following seven divisions of the total area of 903.4 acres. (i) Timberlands bearing commercial stands, 449.0 acres; designated "Engelmann spruce mature" on the original map. (ii) Timberlands bearing noncommercial stands, 24.8 acres; designated "Engelmann spruce subalpine" on the original map. (iii) Young growth, 9.3 acres; designated "Engelmann spruce reproduction" on the original map. (iv) Burned, 26.0 acres. (v) Barren, 197.0 acres. (vi) Brush, 10.7 acres. (vii) Grasslands, 186.6 acres.

Figure 2 shows the outline of the area and the several divisions mentioned. This map has been modified from the original Forest Service survey

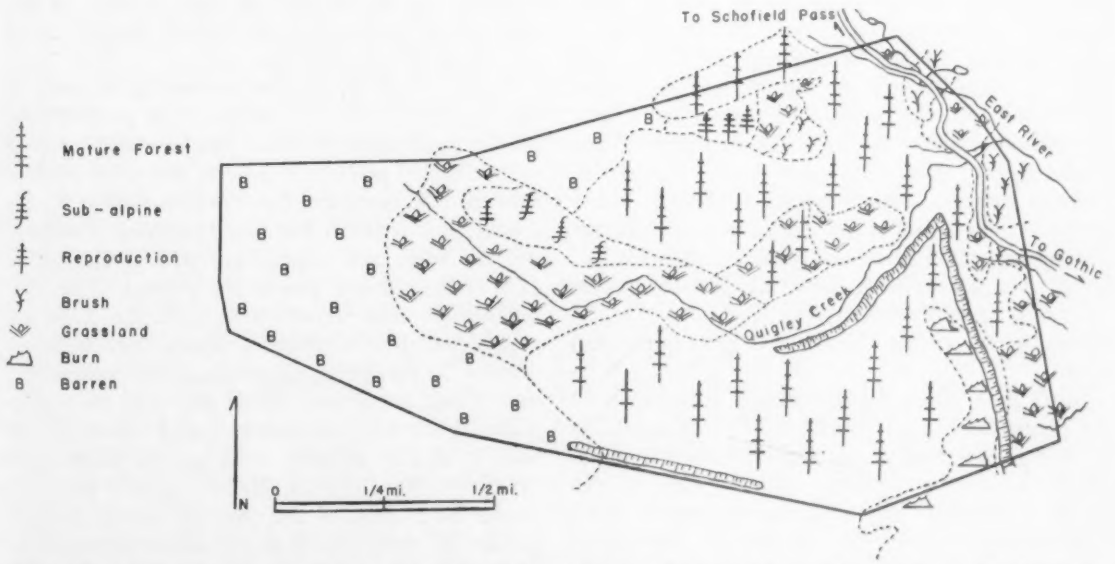

Fig. 2. Map of the Gothic Natural Area. [Based on original Forest Service Map on file at Ranger Headquarters, Crested Butte, Colo.]

Fig. 3. Panorama of the western portion of the Gothic Natural Area. At the left, the mature forest; at the crest, a portion of the barren area; at the right center, grassland with the reproduction area above.

map. Figures 3 to 7 show views in these regions.

The largest division of the area, the virgin forest, consists of Engelmann spruce, *Picea engelmannii* (Parry) Engelm., and subalpine fir, *Abies lasiocarpa* (Hook.) Nutt. The forest is rather uniform in appearance. There are many fir trees of small diameter that are generally young and fewer larger, older spruces. In the understory, no true shrub layer is present because the shrubs are low-growing and blend with the herbs. The shrubs are chiefly *Vaccinium myrtillus* L. (*11*), which at some places is dominant. *Lonicera involucrata* (Richards) Spreng. Rehder, several species of *Ribes*, and a very few individuals of *Sambucus racemosa* L. are also present. The herbs are typical of this kind of forest. *Arnica cordifolia* Hook. has greatest coverage, but *Streptopus amplexifolius* (L.) D. C., *Pedicularis racemosa* Dougl., and others are common.

More than 186 acres of the area are classed by the Forest Service as "grassland." The grassland is divided into several parts, and vegetation is somewhat different in different regions. One of the divisions is particularly signficant because it is almost totally enclosed by timberland. Geological conditions do not seem to be responsible for its presence, for the porphyry sills that give this open area its steep and rocky nature are continuous through the adjacent mature forest. At an elevation of about 11,000 feet, the woodland gives way to an open region that is similar to the other grasslands but which changes into an alpine meadow at higher levels. Patches of snow remain in this region until late in the summer and the vegetation is correspondingly delayed.

Grasses show the greatest percentage of cover in this region, and *Bromus ciliatus* L. is probably the most common species. Other species with a cover of more than 10 percent include in the order of their numerical importance, *Lathyrus leucanthus* Rydb., *Thalictrum fendleri* Eng. var. *fendleri, Potentilla gracilis* Nutt., and *Ligusticum porteri* C. and R. (*12*). Many showy plants are present. They frequently are more conspicuous than the dominant plants and give a changing appearance with the seasons. In the spring *Claytonia, Erythronium,* and such forms are showy. These give way to *Delphinium, Mertensia, Heracleum,* and others in the middle of the summer, and to the Compositae (*Helianthella, Erigeron, Helenium,* and so forth) in the latter part of the growing season. Isolated patches of shrubs such as *Sambucus racemosa* L., several species of *Ribes* and *Juniperus communis L.* also occur.

The so-called reproduction area, labeled "young growth" on the Forest Service map, is located at elevations ranging from 10,500 to 10,800 feet and occupies 9.3 acres. The ages of the trees range from 1 to 60 years. From a distance, the trees look like young growth, but on closer inspection are found to consist largely of clumps of young trees growing from old trunks like sucker growth. Further study should determine the factors at work here. There are almost twice as many firs as spruces—in the sample, there were 65 firs ranging up to 6 inches in diameter at breast height and 38 spruces ranging up to 8 inches in diameter at breast height. Only living trees that shaded the transect were counted; consequently, the data do not show the presence of the old trunks. *Vaccinium myrtillus* L. (*11*), the predominant shrub of the mature forest, is the only important one. Lupines, which are typical of open areas at these altitudes, are the prevalent herbs, but they are not important elsewhere in the area. On the whole, the undergrowth is more typical of the mature forest than of the grassland that adjoins most of the reproduction region.

The "subalpine" tract of trees (24.8 acres) extends chiefly along the sill that separates the main portion of the forest from the alpine meadow in the cirque. The stunted spruces and firs in this tract show the effect of the windswept crest. The trees are not dense; the over-all appearance is that of an open woodland. Other species of more than 10 percent coverage are *Vaccinium myrtillus* L., (*11*) *Ligusticum porteri* C. and R. (*12*) and *Erythronium grandiflorum* Pursh. The presence of a rather large percentage of *Erythronium* results from the fact that plants were retarded by the altitude and were still present to be counted.

A small portion of a large burned area lies within the boundaries of the Gothic Natural Area. This region occupies 26 acres above the conspicuous porphyry outcropping in the eastern part of the area. The fire is estimated to have occurred about 1900. Borings from random trees show ages ranging up to 45 years; however, a ring count on one spruce located on the north edge of the burn indicated an age of 165 years. The burn, in contrast to the reproduction area, shows normal, healthy young trees. The numbers of spruces and firs are nearly equal here although fir is slightly predominant. More young trees occur at the northern edge of the burn where it blends into the mature forest, but the number decreases toward the southern border. Some difference is evident in the undergrowth of the dense northern portion, where the shrubs and herbs are rather typical of a mature forest. The vegetation in the southern part of the region resembles that of the grassland. *Vaccinium myrtillus* L. (*11*), several species of grass, *Lathyrus leucanthus* Rydb., and *Epilobium angustifolium* are most plentiful in the burn.

The brush areas were not sampled because they were difficult to penetrate. These regions, which occupy 10.7 acres of the area, are usually associated with the grassland. The major brush region is located at the lower altitude near the northern edge of the area, but other important patches occur at higher altitudes. The brush area is dominated by dense patches of low-growing willows of several species. Associated with these are herbs that are usually those of the surrounding grassland vegetation such as *Delphinium barbeyi* Huth, *Potentilla fruticosa* L., *Aconitum columbianum* Nutt., and *Heracleum lanatum* Michx. In the most typical portions, willows are so dense that only scattered taller plants can exist.

The barren area of 197 acres blends at its base into the alpine meadow around the cirque in which Quigley Creek heads. Only scattered plants are present on the steeper slopes of Pierre shale.

Bogs are found in several of the regions that have been described. An extensive portion of the mature forest on the lower level is wet to very moist throughout the entire growing season from the accumulation of melting snow. Small bogs are scattered in the various other regions. Although the plants in these wet areas include some that are typical of the immediate vicinity, a number of species are hydrophytic and limited in their distribution. In the forest bog, these plants include *Equisetum arvense* L., *Caltha leptasepala* D. C., *Cardamine cordifolia* Gray, *Oxypolis fendleri* (Gray) Heller, and *Senecio triangularis* Hook. In the more open bogs, *Pedicularis groenlandica* Retz, *Habenaria hyperborea* (L.) R. Br., and several species of *Carex* are frequent also.

Conclusion

The Gothic Natural Area offers excellent opportunities for research in the Rocky Mountain spruce-fir forest. Strategically located near the Rocky Mountain Biological Laboratory, it includes a wide variety of habitats with several interesting and unsolved problems. Further studies of a descriptive and ecological nature on these regions can yield valuable records for studies in later years. The area remains relatively unspoiled even though cattle graze in the lower grasslands and hikers and fishermen penetrate it. A few trees in one small corner were cut before the region was set aside as a preserve.

Fig. 4. The mature forest with a portion of the large isolated grassland.

Fig. 5. Panorama of the eastern portion of the Gothic Natural Area. In the foreground, the largest brush region; at the upper right, the mature forest; and at the upper left, the burn.

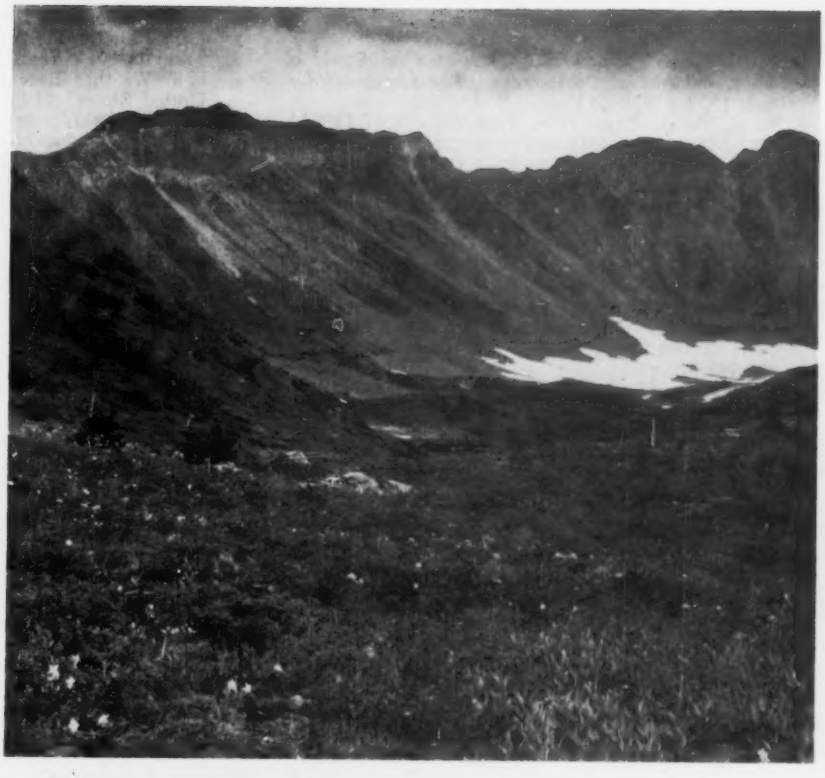

Fig. 6. The cirque at the head of Quigley Creek showing the high meadow surrounded by the barren slopes.

Fig. 7. The sub-alpine region.

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11. This species is difficult to distinguish from *P. caespitosum* Michx. in the field, but it seems to be the predominant one in the area.
12. This species is difficult to distinguish from *Conioselinum scopulorum* (Gray) C. and R. in the field. Probably both are included here.

Benjamin Franklin on Education

Benjamin Franklin, himself, had less than 2 years of formal schooling, yet he helped found two colleges, aided at least half a dozen more, and developed many practical theories of education. He founded the first public library in the Colonies and actively promoted museums and schools for youth.

In his *Proposals Relating to the Education of Youth in Pennsylvania,* which was printed in 1749, he said: "The idea of what is *true merit* should also be often presented to youth, explain'd and impressed on their minds, as consisting in an *inclination* join'd with an *ability* to serve mankind, one's country, friends and family; which *ability* is (with the blessing of God) to be acquir'd or greatly encreased by *true learning*; and should indeed be the great *aim* and *end* of all learning."

And in a letter to Samuel Johnson dated 23 August 1750 he wrote: "I think with you that nothing is of more importance for the public weal than to form and train up youth in wisdom and virtue. Wise and good men are, in my opinion, the strength of a state far more than riches or arms."

A Biologist Looks at Human Nature

LUDWIG VON BERTALANFFY

Dr. Bertalanffy received his Ph.D from the University of Vienna in 1926. He was a professor at the University of Vienna and the University of Ottawa (Canada) and a senior fellow of the Center for Advanced Study in the Behavioral Sciences, Stanford, Calif. Dr. Bertalanffy has published 10 books, partly translated into the English, German, Spanish, and Japanese languages, and is working in the fields of physiology, medical biology, biophysics, and philosophy and history of science. With Franz Alexander, psychiatrist, Dr. Bertalanffy is now directing a new psychosomatic research institute at Mt. Sinai Hospital, Los Angeles.

BIOLOGY, in the usual college curriculum, consists of looking, under the microscope, at amoebas and paramecia and dissecting earthworms, dogfish, and an odd number of other animal species. The trouble with conventional training in the natural sciences is that it presents well enough a smaller or larger body of facts and methods but carefully skips those questions and results that have a bearing on our picture of the world and man (*1*).

To a large extent my personal experience has been with medical schools, and I have found it extremely difficult to persuade the professor of medicine or surgery, the gynecologist, or even the anatomist that modern biology can do somewhat better than present a number of rather irrelevant facts for use on examinations. I am afraid that a similar conception of biology is prevalent also among many behavioral and social scientists. In fact, biology is one of the foundations of behavioral science. To begin with, it will be well to make clear in what sense this is true.

Levels of Science

Without entering into epistemological niceties, we may say that the field of science consists of three levels: physical nature; organisms; and human behavior, individual and social. In the way of an idealized graph, the scale of nature may be represented as is shown in Fig. 1.

I shall not discuss the question of how these levels are connected. It appears that they represent distinctive steps, although not discontinuities, somewhat in the way the mathematician speaks of step functions. There are intermediates between the levels of inanimate and living nature, such as the viruses, and again intermediates between animal behavior and the symbolic behavior characteristic of man. There is no doubt, however, that the notion of emergence is essentially correct. Each higher level presents new features that surpass those of the lower levels.

Here a first important consideration arises. The quest for the unity of science often has led to the postulate of reductionism: namely, that biology should eventually be reduced to physics and chemistry, and that the behavioral and social sciences should be reduced to biology. Now biologism, the thesis that human behavior should be reduced to biological terms and laws, is, in some respects, a much more serious affair than physicalism, the tendency to reduce biology to physics and chemistry. The question whether biological terms and laws can be expressed by the terms and laws of physics is a fine playground for mental calisthenics and an academic problem to be settled by recourse partly to epistemological analysis and partly to concrete research. The question whether human behavior can be expressed in biological terms is far from purely academic. If we assume that the thesis of biologism is correct, it follows that human behavior is to be considered a particularly involved complex of the ways and factors of behavior that are present in subhuman species, in the same way that, for physicalism, a living organism is a particularly intricate physical system. If human behavior and history are only a product of biological factors, one of the most important factors must be heredity. What really matters, then, is not the individual or the culture but the hereditary substratum of the nation or race, and this quite logically leads to the notion of a master race and eventually to the justification of extinguishing others.

If man is to be considered only from a biological viewpoint, war appears as the continuation of the omnipresent struggle for existence. Since, according to current biological theory, survival and selection in the struggle for existence are the principal motors of evolutionary progress, war appears to be the touchstone for the value of a nation or race,

and the surviving one has by this very fact proved its superiority. If human behavior and society have, in principle, the same bases as animal behavior and society, it follows that the most desirable form of society would be one like that of ants or termites. Actually these are much more perfect and satisfactory than human society, since there is no social question, unemployment, or frustration of individuals. In other words, what really matters is not the individual but the supraindividual whole of the state, nation, or race. Then the human individual becomes an expendable short-lived cell in the all-important whole.

These consequences, the theory and practice of a master race, total war, and the totalitarian state, are quite logical once the thesis of biologism is accepted. Of course, other and more ingratiating doctrines can be derived equally well from biological considerations. However, if biological categories are taken as the only measure, such consequences do arise easily and actually have in recent history.

Refusing biologism does not mean that we can neglect biology as the most important groundwork of behavioral science. The situation is similar to that in biology. Hardly any modern biologist will contend that a simple application of physics and chemistry will explain the working of a living cell or organism. No biologist can work intelligently or hope to discover even a shred of the laws governing living things if he does not thoroughly apply physical and chemical knowledge, methods and principles, to the extent that a modern biological laboratory is hardly distinguishable in appearance from a laboratory of physics or chemistry.

It is in this vein that I wish to give a bird's-eye view of some biological fields that are of importance to behavioral science. This survey may be conveniently organized under the aspects of the evolutionary, developmental, neurological, and symbolistic foundations of human behavior.

Evolutionary Foundations

The ancestral series of man is not established quite so well as that of the horse or the elephant but it can be followed fairly closely. There is no need to elaborate in this brief presentation on our knowledge of the descent of man. However, one thing to be mentioned is the preservation of primitive anatomical characteristics in the human organism. An example is the hand (which still shows the primitive ground plan of the five-fingered mammalian) and the vertebrate limb, as compared with the specialization found in the hoof of ungulates, the fin of aquatic mammals, and the wing of bats. Another primitive feature is the preservation of

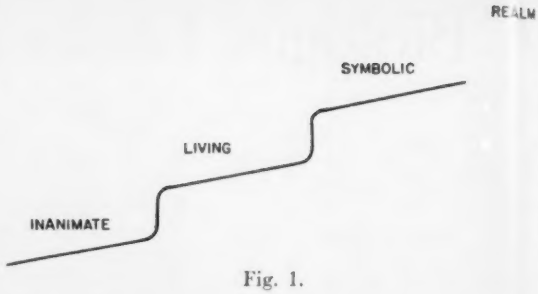

Fig. 1.

pronation and supination of the forelimb in man, as opposed to the fixation of the pronate position of the radius and ulna in other mammalian orders. This, together with the opposability of the thumb, makes the hand the versatile instrument of *Homo faber*. A similar primitivity and lack of specialization is preserved in the teeth. The low specialization and relative reduction of denture, as compared with the anthropoids, leads to the subordination of the facial cranium to the braincase in man.

Progressive changes, on the other hand, are the increase in the size of the eyes, the reduction of a brutish muzzle, and the forward shift of the eye axes. This makes possible the overlapping of the fields of vision of both eyes and is the basis of binocular vision and perception of spatial depth. The evolution of erect posture and gait not only led to transformation of the hind leg but also made the hand free to become a prehensile organ, a change further reflected in the evolution of the brain. It also unburdens the musculature of the neck and leads to the reduction of the cranial relief that is so prominent, for example, in a gorilla's skull. It may be mentioned that even in modern man erect gait is not perfectly established. A number of pathological changes, such as flat feet, hernias, varicose veins, and certain women's diseases, are a consequence of this fact.

In view of the intercorrelation of these and many other characteristics, it is difficult to indicate the primary factors in the evolution of man. Two features, however, appear to be of outstanding importance. One is a change of the hormonal balance, which, ontogenetically, leads to a retardation of development and, phylogenetically, to a conservation of primitive characters. The other is the increase in brain size.

Bolk has emphasized that human development, if compared with the development of anthropoids, appears to be retarded in a number of characteristics. For example, the skull of the baby chimpanzee is much more human than that of the adult chimpanzee with its massive prognathism, heavy eyebrow arches, and so forth. On the other hand,

disturbances of the hormonal balance may lead to a reappearance in man of such simian characteristics as prognathism, hypertrichosis, and precocious puberty. It has been said that man is a "sexually matured anthropoid fetus." This statement, like the news of Mark Twain's death, is slightly exaggerated. Recent studies by Kummer (*2*), using D'Arcy Thompson's method of coordinate transformation, have shown that the human skull cannot be considered simply as a product of "fetalization" of the anthropoid skull. Rather, it is differentiation in another direction, owing to the increase in size of the brain and the neurocranium.

But, even though Bolk's formulation is oversimplified, there is no doubt that the general principle of retardation is correct in many respects and that it has important consequences for man's position in nature.

Animals are anatomically adapted to a particular environment. A horse is an animal of the steppe, a whale is a natant animal, a monkey is an animal climbing in the forest. In contrast, man has preserved many primitive features and has not developed highly specialized adaptations. According to von Uexküll's doctrine, the organization and specialization of an animal is decisive for what enters into its ambient world. Of the great cake of reality, an animal cuts a slice, so to speak, of what becomes stimuli, to which it reacts in correspondence with its inherited organization. The rest of the world is non-existent for that particular species. In contrast to the organization-bound ambient of animals, man has a universe, to use an expression of Gehlen (*3*). Any section of the world, from the galaxies that are inaccessible to direct perception and biologically irrelevant down to the equally inaccessible atoms, can become an object of interest to man. Thus man makes a virtue out of his biological helplessness. Precisely because he is lacking organic and instinctual adaptation to a specific environment, he is able to conquer the whole planet from the poles to the equator. So man creates his own ambient, which is what we call human culture. This, however, would be impossible without a second basic factor: the growth of the brain.

The increase of brain size in the series of mammals is probably the most important example of orthogenesis—that is, evolution in a certain direction. It follows the principle of allometric growth that generally governs the increase in the size of organs with increasing body size. As an over-all approximation, it appears that brain size in the series of mammals "from the mouse to the elephant" is roughly proportional to the 2/3 power of weight; that is, it follows the surface rule that is characteristic of many physiological processes (*4*). In detail, there are complications not settled in an extensive and somewhat controversial literature. (For a review of recent theories on the increase of brain size, see *5*.)

According to the classical theory of Dubois, the increase of brain size is composed of two factors. First, so far as closely related species are concerned, brain size increases allometrically with body size. Second, if different mammalian orders are compared, there is progressive cephalization—that is, a jumplike duplication of brain size with the transition from one group to another. Thus, in the series of shrew, mole, primitive and higher ungulates, anthropoids, *Pithecanthropus,* and man, brain weight (calculated for equal body weight) increases in a ratio 1 : 2 : 4 : 8 : 16 : 32 : 64. Dubois' theory is not to be regarded as proved or generally accepted, but there is little doubt that the evolution of the brain follows rather simple mathematical laws.

In absolute size the human brain is one of the largest, surpassed only by such giant forms as the whale and the elephant. In its relative size, or brain weight per unit of body weight, it is at the top of the series; relative brain weight is larger only in a few small mammals and birds, in which obviously brain size is correlated to the high intensity of their metabolism.

The allometric growth of the brain in the series of mammals amounts not only to a quantitative increase but, as Rensch (*6*) has recently shown, further entails changes in the architecture of the brain, providing cerebral areas that can be used for higher functions. It also leads to histological changes and possibly differences in view of instinctive and learning behavior. It may be mentioned in this connection that the ventral region of the frontal lobe, where the motoric speech center is localized, is lacking even in anthropoids and appears only in man. In contrast, the temporal lobe, where, in man, the sensory speech center is located, is rather well developed in animals. Consequently, animals like the dog, the elephant, or the horse learn to obey spoken commands and, so, obviously have acoustic gnosia of speech, which is lost in dogs after destruction of this region. The possession of the motoric speech center is connected with the verbal and symbolic abilities of man.

Growth and Development as Bases of Behavior

Let us now take a look at growth and development as bases for human behavior. Growth, in its quantitative aspects, can be considered under two major viewpoints: growth in time, the increase of measurable quantities in the organism as a function of time; and relative growth, the ratio between dif-

ferent growth rates of parts in an organic system which eventually leads to changes in proportion. I have already discussed an evolutionary aspect of relative growth as shown in progressive cephalization.

The time curve of growth in mammals, fish, crustaceans, clams, and other animal classes follows a pattern, which is characterized by the fact that it approaches a final weight by way of an S-shaped curve. These characteristic growth curves, as well as different ones found in other groups, such as insects and snails, can be explained and predicted by a theory of "growth types and metabolic types" (*5, 7*), which, in principle, is based on the consideration of growth as the result of a counteraction of the building up and breaking down (anabolism and catabolism) of the body constituents. Since its pattern is essentially the same, the growth of different species, such as a fish, a mouse, an elephant, or man, can be represented by the same curve. Only the scales of units of time and size are different.

In such comparison, only one organism, man, makes an exception. In its first part, the human growth curve is distinguishable from that of all other animals in that a growth cycle seems to be added, so that the infant period is greatly prolonged and the steep, almost exponential increase in size, as is characteristic for early postembryonic growth in animals, is avoided. This difference in the growth curve may appear to be an insignificant detail, but it has tremendous consequences. The abnormal shape of the human growth curve is, of course, a quantitative expression of the retardation and hormonal shift mentioned earlier. Thus animals run swiftly through the period of their somatic and behavioral growth, and soon sexual maturity is reached. In contradistinction, the characteristic shape of his growth curve gives man his uniquely long period of youth and the opportunity for a long period of learning and mental development. It is an indispensable prerequisite of human culture.

This is connected with another interesting characteristic. We can distinguish in birds and mammals between nidifugous and nidicolous species: those in which the young reach independence and leave the nest early or those that are born in a rather undeveloped state and need parental care for a long period. Compare a kitten born blind and helpless with a young colt. This difference depends on the index of cerebralization—that is, the ratio of the hemispheres to the brain stem. Nidifugous species are the more advanced forms with higher cerebralization. Man, as Portmann (*8*) has emphasized, represents the unique case of a secondary nidicolous. Corresponding to his high cerebralization and owing to his long gestation period, he is born at a stage that would anatomically correspond to that of a nidifugous animal. Nevertheless, behaviorally he is nidicolous. Here we possibly have one important biological root of mother fixation, the Oedipus complex, and other psychoanalytic items. The role of the "biological helplessness" of the infant has already been emphasized by Freud (*9*). The human baby needs and receives extensive maternal care at a time when his sensory and neural equipment is well completed. This is a situation that is rather unique in the animal kingdom. Perhaps even the suggestion can be made that this early fixation is of the nature of an imprinting mechanism in the sense of Lorenz (see *10*), fixing an image in a state that is advanced enough neurologically to make this possible but early enough that such rather primitive determination of behavior can still take place.

In passing I would like to mention that, in all probability, the somatotypes of man are essentially a phenomenon of relative growth. One cannot speak of a cycloid or schizoid personality without taking into account the theory of body constitutions as developed by Kretschmer in Germany and by Sheldon in this country. In their present stage, these theories are certainly exposed to serious criticism. However, the typology of somatic constitutions and their connection with psychological predispositions and mental diseases, as formulated independently by different authors, shows close correspondence, and this is an indication that, to a certain extent, it corresponds to reality. As Conrad, a follower of Kretschmer, has emphasized, the somatotypes are the expression of a different harmonization of growth rates, "bundles of correlated growth principles." It is remarkable that Conrad's analysis (*11*) of the types of constitution in man closely approaches the conceptions of a "dynamic morphology" that I developed (*12*) in the rather different fields of comparative physiology of metabolism and growth.

Evolution of the Brain

Speaking again in the way of a crude oversimplification, which is likely to incur the well-deserved indignation of the neurologist, the neurological evolution in vertebrates can be conceived of as being a superposition of three major levels of neural apparatus piled up in the course of evolution. The oldest part is the spinal cord, which is present in *Amphioxus* as a rather remote ancestral form and is essentially an apparatus of reflex response. Superimposed on the spinal cord, the brain develops in the series of vertebrates. This evolution takes place

in two major steps. In accordance with the increasing development of sense organs, massive ganglia are developed at the anterior end of the spinal cord as an apparatus to react to sensory stimuli. This primeval part of the brain, known as the paleencephalon, is present almost alone in the fishes, but it keeps its importance as far as man. Superimposed on it, the enormous neural structure of the cerebral cortex gradually develops. This so-called neencephalon is only rudimentary in fish and increases continually in the series of amphibians, reptiles, birds, mammals, and man.

In man the paleencephalon becomes the organ of primitive functions and the mediator between the cortex (the organ of consciousness) and the neurohumoral system. The cortex is the organ of the day personality of conscious perception, feeling, and voluntary control of action and, in particular, of the symbolic activity characteristic of man.

This, however, has certain gloomy aspects. If we survey the evolutionary series of brains from the lower vertebrates to man, the characteristic is progressive cerebralization—that is, the increase in the quantity and complexity of the forebrain. What is called human progress is a purely intellectual affair, made possible by the enormous development of the forebrain. Owing to this, man was able to build up the symbolic worlds of speech and thought and some progress in science and technology during the 5000 years of recorded history was made.

Not much development, however, is seen on the moral side. It is doubtful whether the methods of modern warfare are preferable to the big stones used for cracking the skull of the fellow-Neanderthaler. It is rather obvious that the moral standards of Laotse and Buddha were not inferior to ours. The human cortex contains some 10 billion neurons that have made possible the progress from the stone axe to airplanes and atomic bombs, from primitive mythology to quantum theory. There is no corresponding development on the instinctual side that causes man to mend his ways. For this reason, moral exhortation as proffered through the centuries by the founders of religion and great leaders of humanity has proved disconcertingly ineffective. If moral progress is possible, it seems so only in the way of inhibition and sublimation. The inhibitory action of higher centers on lower ones is a well-known fact in neurophysiology. It appears that we cannot change the *bête humaine*: we can only hope that the brute in man is better controlled.

Dominance of Symbols

"Everything in this world is nonsense; the whole of life is a plethora of ludicrous absurdities, one more fanciful than another. The crown is nothing, the ring is nothing, too. Each would mean nothing but nonsense and empty foolishness except to the eyes which behold the symbolism behind them. Yet they, because of their meaning, dominate the world. Only one form of metal there is, which is a meaning in itself—the sword," said Temple Thurstone (*13*).

What is unique in human behavior? The answer is unequivocal and generally accepted. The monopoly of man, made possible by the evolution of his forebrain that profoundly distinguishes him from other beings, is the creation of a universe of symbols in thought and language.

Man's unique position is based on the dominance of symbols in his life. Except in the immediate satisfaction of biological needs, man lives in a world not of things but of symbols. A coin is a symbol for a certain amount of work done, or food and other utilities available; a document is a symbol of *res gestae*; a word or concept is a symbol of a thing or relationship; a book is a fantastic pile of accumulated symbols; and so forth *ad infinitum*.

Symbols can be defined as signs that are freely created, represent some content, and are transmitted by tradition. It appears that the characteristics indicated are necessary and sufficient to distinguish symbolism, and language in particular, from subhuman forms of behavior.

By "freely created" I mean that there is no biologically enforced connection between the sign and the thing connotated. In conditioned reaction, the connection between the signal and thing signaled is imposed from outside. It may be a natural connection, as when a child or kitten seeing a flame moves to avoid the fire, because the child or the kitten has previously been burned. Or the connection may be arbitrary and imposed by the experimenter, as in the case of the Pavlovian dog that learned to secrete saliva when a bell was rung because this was followed by a meal during the conditioning period. In contradistinction, there is no biological connection between the words *father, pater, père, otec* (or whatever the word may be in any language) and the person so designated. This does not imply that the choice of symbols is completely arbitrary; probably it is determined by little known psychological principles.

Furthermore, a symbol connotes or represents a certain content and thus is different from language as expression or as command found also among animals. A bird's song expresses and communicates to its mate a certain physiological and, we may be sure, psychological state, but it does not connote a thing. The barking of a dog warns of some danger, but it does not indicate whether the source is an intruding burglar or the neighbor's cat.

Finally, symbolism and language are defined as

being transmitted by learning and tradition. For example, the language of the bees, admirably described by von Frisch, is representative. By means of intricate dances, the workers communicate to their colleagues the direction and distance of the place where food may be found. But this language is innate and instinctive. We can teach a dog all sorts of tricks, but we have never heard that a particularly clever dog has taught its puppies to do them.

Not being an anthropologist, I do not venture a hypothesis on the origins of symbolism and human language. I have a strong suspicion, however, that they might be found in imitation and magic.

For primitive man, an image, be it material or acoustical, is the original and gives him control and dominance over it. This is the essence of sympathetic magic. Think of a very primitive and common form of magic. A puppet made from clay *is* the enemy, and the enemy can be killed if a needle is thrust into the image. When the paleolithic hunters painted those grandiose frescoes of deer and lions on the walls of caves in France and Spain, we may be sure that it was not just *l'art pour l'art*; but rather a powerful charm for successful hunting.

The same applies to an acoustical or onomatopoetic image. By naming things, man takes possession of the world in their symbolic images. For this reason, Adam's first work in paradise was to give names to animals, plants, and things. Naming a thing gives power over it. In contradistinction, Yahwe's name is unspeakable. For if His name should be uttered, He would be submitted to the will of him who knows it. The sorcerer evokes the demons of hell by calling their names.

Hence, the assumption that the origin of human language was in verbal magic does not seem to be far-fetched. A sound uttered may give some onomatopoetic image of an animal or person or may be connected with some biological function. For example, the word for *mother* begins in nearly all languages, irrespective of their structure, with an *m* (after Kluckhohn), apparently a sound connected with the smacking by the baby at the mother's breast. Thus a sound may become an image of a thing. Consequently, the sound will be identified with the original just as the clay image is identified with the enemy, and then uttering the sound will govern the thing designated. Thus, language may be born of magic, a process certainly infinitesimally slow in its beginnings, but man has had many hundred thousands of years at his disposal to come from an anthropoid to *Pithecanthropus, Sinanthropus,* and *Homo sapiens.*

Whatever the origin of symbolism, its consequences are enormous. The first consequence is obvious. Phylogenetic evolution, based on hereditary changes, is supplanted by history, based on the tradition of symbols. In the biological sphere progress is possible only within an evolutionary time-scale. For example, the societies of ants have remained unchanged for the past 50 million years. In contrast, human history has a time-scale of generations, comprising almost all high cultures in a span of 5000 years, and it may even be thought that cultural time has a logarithmic, rather than an arithmetic, scale with changes taking place at an ever-increasing pace.

Second, corporeal trial and error as found in subhuman nature is replaced by reasoning—that is, trial and error in conceptual symbols. An animal placed into a maze, faced with a complicated lock or confronted with some other problem, runs around until it finds the way out. It tries until the mechanism of opening the door or the solution of the problem is discovered by chance. Then the way leading to success is gradually fixed. Man in a corresponding situation sits down and thinks; that is, he experiments not with the things themselves but with the symbolic images of things. He scans different possibilities, discounts those that seem ineffective without laboring to try them materially, and accepts the apparently successful solution as the basis for overt behavior. The interpretation of thought processes as substitutes for experimental actions was maintained by Freud (*14*).

A third and more profound consequence of symbolism is that it makes true purposiveness possible. Purposivenesss in a metaphorical sense—that is, regulation of function in the way of maintenance, establishment, and reestablishment of organic order—is a general characteristic of life. It is based on such principles as equifinality of the steady state of the organism, homeostatic feedback mechanisms, learning by trial and error and conditioned reflex, selection in evolution, and so forth. But even in the most amazing phenomena of regulation and instinct we have no justification for and definite reasons against the assumption that these actions are carried through with foresight of the goal. This true or Aristotelian purposiveness is unique to human behavior and is based on the fact that the future goal is anticipated in thought and determines actual behavior.

When man passed the stage of barbarism, he had to realize that verbal magic was impotent. Thrusting needles into the enemy's image did not as a rule kill him. Similarly, a name is just a label attached to a thing and not the thing itself. It is true enough that relics of primeval verbal magic are still with us, much more than is desirable. In speak-

ing a "nation," "state," or "party," we behave as if those names were things, whereas actually they denote personificative fictions, hypostatizing groups of individuals with their egoistic interests, little intelligence, and exaggerated passions for mythical entities.

If verbal magic was deceptive, another sort of symbolic magic was discovered that was extremely powerful. We may call it the magic of the algorithm.

An algorithm is a system of symbols connected according to preestablished rules. Take the simplest example, the name of whose propagator, al-Khowarizmi, is immortalized in this word. This is the decimal notation. In Roman numbers even a trivial multiplication, such as LXXVI × XCIII, is quite a formidable operation. However, the simple trick that the last digit of a number in Arabic notation means units, the second tens, and so on, and that corresponding figures are written in columns makes the operation child's play. Thus an algorithm means a machine of thinking, performing operations by suitable connections of symbols, and giving results difficult to attain or unattainable otherwise. Or, conversely, calculating and thinking machines, mechanical or electronic, are only the materialization of algorithms. Algorithmic magic is commonly known as science and scientific technology.

So long as symbols stand alone they are unproductive and do not convey more information than that contained in the individual symbols. Thus in the flag-language used by seafarers each flag symbolizes a certain fact or command, but an array of flags is just the sum of the individual meanings.

This is profoundly altered if symbols are combined according to established rules of the game, if they are elements in an algorithm or, as we may say, if a language has not only a "vocabulary" but also a "grammar." Then the system of symbols becomes productive and fertile. With a suitable choice of terms and of rules presupposed, we can handle the symbols as if they were the things they represent. If the symbols, as well as the grammar, are well chosen, the result of the mental operation of symbols will correspond to that of the real course of events. The consequences of the images will be the images of the consequences, to use Heinrich Hertz' expression.

In this way a true magic is possible with systems of symbols. We can predict facts and relationships still unknown, can control still unrealized combinations of natural forces, and so on.

Science, to a large extent, consists in the invention, elaboration, and application of suitable algorithms. Trivially the algorithm of physics is mathematics in the ordinary sense. But the language of, say, chemical formulas or of genetics also represents algorithms suitable for the particular realm. The same is true even if the system is remote from what is ordinarily called mathematics, as is the Linnean system of classification. With its binary nomenclature, the classification of organisms into species, genera, families, classes, and so forth, is also an algorithm symbolically representing certain aspects of reality—the manifoldness of, and relationships between, animal and plant forms, allowing to a certain extent for scientific prediction.

The universe of symbols, although created by man, wins a life of its own, as it were. The development of the Roman law, the British Empire, the atomic theory from Democritus to Heisenberg, or of music from Palestrina to Wagner, is certainly borne by a number of human individuals. But it shows an immanent logic that widely transcends the petty personalities, the human and all-too-human creators.

This autonomous life of the symbolic world has a most important positive aspect. The symbolic universe becomes, so to speak, more clever than man, its creator. Thus the symbolic system of language, and particularly of the artificial languages called mathematics and science, develops into a colossal thinking machine. An operational command, a hypothesis with the necessary specifications, is fed in; the machine starts to run and eventually by virtue of preestablished rules of the connection of symbols, a solution drops out which was unforeseeable in the individual mind with its limited capacity. This is the general characteristic of scientific reasoning, be it a simple arithmetic operation or the solution of a differential equation, the prediction of still undiscovered planets and chemical elements, or the construction of some masterpiece of modern technology.

Besides these triumphs of symbolism, there are, however, its pitfalls. The conceptual anticipation of future events that allows for true purposiveness is at the same time the origin of anxiety in regard to the future and fear of death, which is unknown to brutes. The invention of the symbolic world is the fall of man. The notions of sin and evil arise with the invention of symbolic labels attached to certain forms of behavior. War also is a human invention. It is not a biological phenomenon, the continuation of the omnipresent biological struggle for existence. Even if nature were "red in tooth and claw," which it is only to a limited extent, organized intraspecific warfare would still be unknown in the subhuman world. Apart from the rather rational strifes of savages who go out and kill enemies in order to eat them, war is caused by

head hunting, illusions of grandeur, ideologies, economic reasons based upon symbol-charged values, religion—all of them only superficially different kinds of verbal magic. This, however, leads to the ingratiating conclusion that war is not a biological necessity and that it would not be unavoidable if mankind would put its symbolic abilities to better use.

If there is a clash between the symbolic world built up as moral values and social conventions on the one hand, and basic biological drives on the other, then, with respect to the individual, the situation of neurosis arises. Somewhat extending the narrower definition of Freud, it seems that a neurotic situation results from the conflict of a symbolic universe with biological drives, or of opposing symbolic worlds. As a social force the universe of symbols, which is unique in man, creates the sanguinary course of history. Thus man has to pay for the uniqueness that distinguishes him from other beings. The tree of knowledge is the tree of death.

Although I have tried to indicate some biological bases of human behavior, it is impossible to give more than a few glimpses of this tremendous problem here. I have not even mentioned many equally important fields, such as genetics with the question of inheritance of behavioral, mental, and psychopathological traits; nature and nurture; race; ecology with its applications to human populations; the Malthusian problem; the question of providing for an ever-growing humanity; the evolution of animal behavior from unconditional to conditional reflex, instinctive action, and insight and its bearing on human behavior; and many others. In some way or another, it seems that behavioral science is supposed to contribute to the pressing problems of our epoch, not only in the way we invent nice little theories, mathematical models, and so forth, but also in the critical state that the social organism seems to be in at the present time.

Revolt of the Masses

The basic symptom of present society seems to be the uprise of the masses or the proletariat, as is depicted so vividly by authors like Ortega y Gasset and Toynbee. Let us forget for the present discussion about the demographic aspects, the increasing overpopulation of our planet, and the Malthusian threat and concentrate on the behavioral aspect. I believe that a precise answer to the problem can be given in biological terms.

I am inclined to define the "revolt of the masses" as a return to the conditioned reflex. The unique characteristic of human behavior is the ability to make decisions at a symbolic level. This, of course, does not mean that conditioned behavior is negligible. Any human achievement, from toilet training to speech, driving a car, or learning calculus and theoretical physics, is based on conditioning. However, the dignity of man rests on rational behavior—that is, behavior directed by symbolic anticipation of a goal. In modern man, however, this *vis a fronte,* to use Aristotle's term, consisting of goals the individual or the society sets itself, is largely replaced by the primitive *vis a tergo* of conditional reaction.

The modern methods of propaganda, from the advertisement of a tooth paste to that of political programs and systems, do not appeal to rationality in man but rather force upon him certain ways of behavior by means of a continuous repetition of stimuli coupled with emotional rewards or punishments. This method is essentially the same as that applied to Pavlovian dogs when they were drilled to respond to a meaningless stimulus with reactions prescribed by the experimenter. Not that this method is new in human history. What is new, however, is that it is applied scientifically and consistently and so has an unprecedented power. The modern media of mass communication, newspapers, radio, television, and so on, are able to establish this psychological constraint almost without interruption in time, reaching all individuals in space with maximum efficiency. If a slogan, however insipid, is repeated a sufficient number of times and is emotionally coupled with the promise of a reward or the menace of punishment, it is nearly unavoidable that the human animal establishes the conditioned reaction as desired. Furthermore, to apply this method successfully, the conditioning process must be adjusted to the greatest common denominator; that is, the appeal has to be made to the lowest intelligence level. The result is mass-man—that is, abolishment of individual discrimination and decision and its replacement by universal conditioned reflexes. *Brave New World* and *1984* are but paraphrases of this theme.

Obviously there is no easy solution to the problem, and it is wise not to join the quacks who have found the wonder drug to cure the ills and entanglements of humanity. However, precisely because of the predominance of psychological techniques, realization of the motive forces of human behavior becomes the more important. Herein lies the responsibility of the science of human behavior. Besides the menace of physical technology, the dangers of psychological technology are often overlooked. Perhaps even more dangerous than the material existence of the bombs are the psychological forces that may lead to the dropping of them.

As we try to put atomic energy to peaceful use, it may even be more urgent to put to intelligent use the psychological mechanisms revealed by behavioral science (*15*).

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Query for Discussion at Franklin's "Junto"

"How shall we judge of the goodness of a writing? Or what qualities should a writing have to be good and perfect in its kind?

"*Answer.* . . . To be good, it ought to have a tendency to benefit the reader, by improving his virtue or his knowledge. But, not regarding the intention of the author, the method should be just; that is, it should proceed regularly from things known to things unknown, distinctly and clearly without confusion. The words used should be the most expressive that the language affords, provided that they are the most generally understood. Nothing should be expressed in two words that can be as well expressed in one; that is, no synonymes should be used, or very rarely, but the whole should be as short as possible, consistent with clearness; the words should be so placed as to be agreeable to the ear in reading; summarily, it should be *smooth, clear,* and *short,* for the contrary qualities are displeasing.

"But, taking the query otherwise, an ill man may write an ill thing well; that is, having an evil design, he may use the properest style and arguments (considering who are to be readers) to attain his ends. In this sense, that is best wrote, which is best adapted for obtaining the end of the writer."

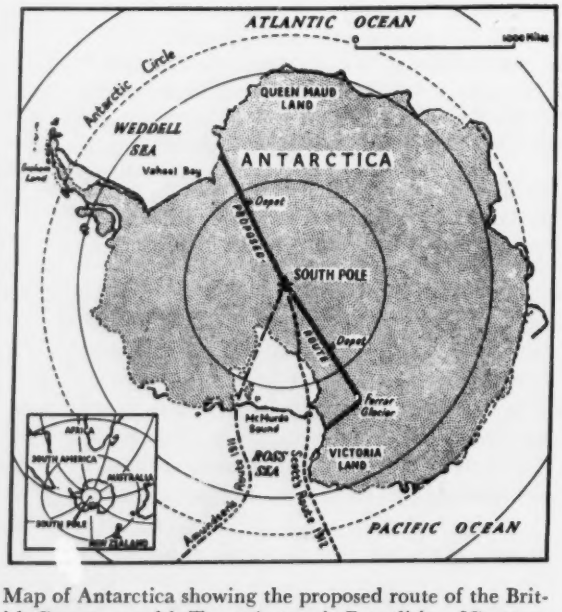
SCIENCE ON THE MARCH

NEW ATTEMPT TO CROSS ANTARCTIC

A SMALL party of men set out from Britain last November on a project long cherished by scientific explorers but never yet fulfilled: the crossing of the Antarctic Continent. Many plans and attempts have been made during the past 40 years —for example, that of Ernest Shackleton in 1914— but all have foundered, usually because of insolvency. However, this latest venture, the Trans-Antarctic Expedition, started out on a different footing—it has the full support of the British and New Zealand Governments, the Royal Air Force, industry, and the general public.

The advance party that left in November is the spearhead of the project that will entail, over a period of some 2½ years, two main camps more that 1800 miles apart. It will cover hundreds of square miles of unknown territory. Scientific observations will be made, maps will be drawn, and new mountain areas will be examined geologically. Seismic echoes will probe the thickness of the ice sheet, and physiologists will examine the men's adaptation to the severities of the climate.

At the two base camps, continuous records will be kept of the weather, and much valuable research will be conducted on short-wave radio transmission. It is also expected that useful experience will be gained in operating aircraft under severe conditions. The land parties will use dog teams and the latest type of tracked vehicles designed for use in snow.



Map of Antarctica showing the proposed route of the British Commonwealth Trans-Antarctic Expedition. [Courtesy British Information Services]

Many enthusiasts have applied to join this Trans-Antarctic Expedition, which is under the command of V. E. Fuchs, a 47-year-old Cambridge geologist. Fuchs, who was the originator of the scheme, is well-known as a polar geographer; he has had practical experience in Greenland as well as in the antarctic. The leader of the second base, which will receive the transcontinental party, is Edmund Hillary, of Everest fame. The whole expedition is predominantly a venture of the British Commonwealth. Financial contributions to the expedition include £100,000 from the United Kingdom, £50,000 from New Zealand, £A25,000 from Australia and £18,000 from the Union of South Africa.

The advance party sailed from London in the 850-ton Canadian sealer *Theron* with eight scientists and technicians and eight observers on board. After the expedition reaches the Weddell Sea, the light aircraft carried on the upper deck of the ship will be used to pick a way through any pack ice that may be encountered. Later it will reconnoiter the ice shelf that fringes the southern shores of the sea, searching for a suitable site for establishing a base.

The prefabricated huts will be assembled at top speed because the antarctic summer is short and treacherous, and at any time the pack ice may come swirling in, forcing the ship to start out to sea. The day the roofs are on and all is secure, the *Theron* will steam north to civilization with the eight observers and the RAF flight. At this time continuous scientific observations will begin, and preparations will be made for the spring journeys to the south.

The main party is scheduled to sail from the United Kingdom in November 1956 under Fuchs' direction, and at the same time Hillary will build the base in McMurdo Sound in the Ross Sea that will shelter some 20 men for the winter. It is hoped that by February parties from the Weddel Sea base will be out in the field laying a depot about 300 miles inland and erecting there on the polar plateau an Ice Cap Station that will be manned by meteorologists throughout the winter. On the other side of the continent, Hillary will be searching for a suitable route up the glaciers to the west and onto the plateau. This is the route that will have

to be followed on the last leg of the crossing party's track.

The winter of 1956–57 will be a busy time of preparation at both bases for the major journeys ahead, for as much work will be done as possible before the scheduled departure of the crossing party. On the Ross Sea side, depot journeys will be in progress with dog teams and aircraft for the support of the party that will come from the other side of the continent.

The crossing party will itself leave in November 1957, equipped with a train of tracked vehicles and dog teams. The principal role of the latter will be reconnaissance in crevassed or mountainous areas where route finding with the heavy vehicles would be very hazardous. The aircraft will support the party up to and possibly a little way beyond the Ice Cap Station and will then wait for good weather to fly across the pole to the McMurdo Sound base nonstop.

The men at the Ice Cap Station will join with the caravan, and the long pull to the pole, which is known to stand at an elevation of more than 9000 feet, will begin. Once over the pole, the party will gradually lose altitude, and it is hoped that Hillary's group will be met at or near a depot near Mount Albert Markham. Both sections of the expedition will then move down the west side of the Britannia Range, which will already have been surveyed and examined by the Ross Sea party, to the head of the chosen glacier for the descent into McMurdo Sound. If the terrain is too difficult, the vehicles will have to be abandoned and the last 100 miles traversed with dog teams alone.

It is planned that this main journey will take 4 months and cover some 1800 miles, most of which will be new ground. But even that will be rather less than half the total mileage of the expedition sledge parties.

March 1958 should see the withdrawal of both parts of the Trans-Antarctic Expedition via New Zealand, the country that has seen the departure and homecoming of so many other expeditions to Antarctica.

D. G. STRATTON

Stores Officer of the Expedition

BOOK REVIEWS

The Crime of Galileo. Giorgio de Santillana. Univ. of Chicago Press, Chicago, Ill., 1955. xv + 338 pp. Illus. + plates. $5.75.

The Crime of Galileo reads like a detective story in modern journalistic style. I highly recommend it for its gripping style. Beginning the oft-told tale one wonders what new facts will be uncovered by the author, who recently translated Galileo's *Dialogue on the Great World Systems.* As far as I can judge (sources are not always quoted; conflicting views are rarely noted and then somewhat caustically), the book is not based on any new evidence. Rather it purports to be fundamentally an entirely new viewpoint.

In the past, either Galileo has been proclaimed a martyr for science, or the Church has been praised as a bulwark for religion. In the present interesting account Galileo is portrayed as a defender of the Faith in spite of the Church. The author urges that "Galileo did not come to grief as the scientist facing a religious credo." "He was an intelligent man who had taken every risk to force an issue and to change a policy for the good of the Faith." He hoped "to force Urban's hand ever so little." "What Galileo was begging for was pitifully small; that the authorities should have kept judgment suspended for another generation or for another few years at least." "At the hour of what he knows to be scientific victory Galileo is generously throwing the mantle of his intellectual prestige around the authorities so as to cover their past incompleteness and obduracy." "If Galileo had found Saint Bonaventure instead of Saint Robert Bellarmine still in the seat of theological authority, he might have become a pillar of the Church."

In this melodrama Galileo is usually the hero—except when he is physically broken down. His actions are always excusable, those of his opponents ever intolerable. Even in the last chapter we are told that "the abjuration is not all the surrender and moral disgrace that self-appointed judges have made it out to be." It was "not considered a moral degradation. It was a deliberate social degradation." In other words, even if Galileo did not say *"E pur si muove,"* as he rose from his recantation, he thought it then and thereafter. The proper question here, I suppose, is one's own concept of ethics.

It is soon evident to the reader that a case is being summarized by an attorney for the defense in a fascinating manner with free use of innuendoes. He labels Galileo's opponents "an unscrupulous group of power politicians," "an extremely capable outfit of hypocrites," "a pack of liars," "scoundrels, liars, and forgers of solidly established reputation," "provocateurs," "authorities gone off the deep end," "a spoiled amateur of absolute power who was playing by ear."

The author speaks of the actions of the opposition as follows: "a churlish planned aggravation," "a third-hand denunciation by an informer," "spotting by 'Objective Characteristics,'" "trumped up charges," "intentional inaccuracy," "a calculated leak," "legal rail-

roading," "a slick job," "Lorini's badly forging a couple of heresies," "an indecent and fascinating piece of judicial skulduggery," "plain filth." He visualizes "a masterful plan conceived apparently by Lodovico delle Colombe," "a League for Conspiracy led by the Lorini-Caccini-Colombe triumvirate," "the operation went into second phase according to plan," "the third phase of the combined operation came in with perfect timing."

The motives of Galileo's opponents are variously described by phrases such as "personal ambition, vanity, self-pity of his relatives," "the subversive in his minklike cunning," "pressing for judicial slaughter," Tommaso Caccini "out to get Galileo by fair means or foul," "hitting him below the belt," "a decision to spring the trap." The author declares "he had banged his fists publicly upon the table and ordered the ad hoc Commission to produce a case against that man on the double quick," "he had lost his head," "it was going to be a showdown," "a desire to humiliate that gang for all to see."

Galileo, however, is seen as "having outmaneuvered his opponents," "having his name dragged in the mud," "obviously terrified." We are made to understand that "the old man has stood his ground desperately."

The amazing part of this story is the climax. The crime, it turns out, is not that of Galileo at all. At most, "Galileo's crime lay in having perceived that change in the new things of science could not be so slow as expected." It was the prosecution apparently that had determined that "nothing really would do except a theological crime, attributed unjustly to Galileo." The real crime, we are at last informed, had been committed by the Commissary General during the visit of Galileo to Rome in 1616. Ingeniously the author shows how such a case can be constructed.

Where there is no direct evidence, he skillfully reconstructs the very mode of thought of the witnesses. With respect to the early talks between Urban VIII and Galileo, the author admits that "what took place in those audiences will forever remain a matter for speculation." Yet, he will introduce a subject with the remark, "We see thoughts racing through his mind." One cannot help wondering how right the author's surmises are. For example, he would have us believe that as early as the time that Galileo sought the laws of missiles and of falling bodies, "He had told himself he would not show his hand in cosmology until he could come forward as an entirely new type of Copernican." Later we are told that "he was pleading . . . for the rights of scientific imagination to follow its quest for the secrets of universe wherever it led; and this meant inevitably invading the reserved field of metaphysics." Toward the end he says, "One wonders what Galileo's thoughts must have been." The author then tells us "he guessed that this was the end of the whole scientific movement in Italy." I personally wonder, in turn, whether the author's interpretation here is correct. Certainly Galileo's supposed guess was not!

With respect to Niccolo Lorini he notes, "In his heart, however, he felt otherwise; they were black souls who did not deserve justice." "From Castelli's dark allusions it is easy to infer that the Jesuits advised by Grassi and Scheiner had swung into action." The author apparently does not trust the reader's likely interpretation of a statement. He feels he must restate it to be certain that its significance fits into his own theory. For example, "Whatever the words, this was the gist of it." "This meant 'If you want to bring about an international incident, please go ahead and suit yourself.'" "His real statement," we are told, "is very different from what a modern reads into it." Melchior "Inchofer's report may look to the modern reader more objective than it is." So the author hastens to illustrate the real meaning, as he sees it, in the seven-page report by the Counselor of the Inquisition. In all this fictional history one feels that some of the social concepts being applied by the author are anachronistic in spirit if not in fact.

The author claims that the Dominican, Michelangelo Segizi de Lauda, provided "a toehold for prosecution if that were needed." The "crucial piece of drama," "the king pin in this case," is taken by de Santillana to be the 26 February 1616 "administrative minute," "unsigned," "casually transcribed," which from the time of F. Reusch has been recognized as a legally perplexing but historically significant document (it was written on the back pages of two other documents). Other historians had early objected to this fateful document as being spurious and as having been concocted in 1632, a supposition that has now been satisfactorily disproved. De Santillana, however, would make it foreseen in 1616 that the forged document might be useful in 1632. This explanation looks ad hoc, despite the author's urging that "they were not above such methods—there is quite a number of precedents." The moot point is whether this document is indicative of an actual injunction that "he must neither hold, defend, nor teach opinion in any way whatsoever." There is much controversy, too, over the legality of the inclusion of the words "teach . . . in any way whatsoever," which were omitted in Bellarmine's certifying letter to Galileo in 1616. To me, it seems that the noncontroversial words, *hold, defend,* are even more significant, if we are to judge Galileo at the present bar of human understanding rather than in the past Court of the Inquisitor.

The story told by the author is as plausible as other accounts; undoubtedly the "real story" is latent in the totality of all viewpoints. One cannot help wondering here, however, whether the author is really viewing the circumstances that occurred in the hazy light of long ago or in the revealing light of subsequent developments—particularly later scientific achievements.

Take the heliocentric hypothesis, for example. It was not new with Copernicus or scientifically original with Pythagoras. Aristarchus has been more rightly called the "Copernicus of Antiquity." The replacement of the 84 circles of Ptolemy with the 34 circles of Copernicus is obviously a mathematical gain but hardly a physical one. Moreover, the telescopic discoveries of Galileo revealed primarily evidence against the Aristotelian view of an unchanging heaven but not so much direct evidence for the Copernican theory itself. It is certainly

not true that "anyone looking at Jupiter through a telescope saw right there in the visual field a solar system demonstrated on a small scale." (It might just as well be called an analogy to a geocentric system.) As for the phases of Venus, these can be accounted for by both geocentric and heliocentric hypotheses. Galileo's primary argument of the tides being caused by unequal velocities of the earth's surface due to rotation and revolution made the Copernican hypothesis plausible but not conclusive. (It is noteworthy that this theory, for which Galileo wished to name the book "On the Flux and Reflux of the Sun," until refused by Urban VIII, has proved to be incorrect.) Even the sunspots were more concerned with the rotation of the sun than with its revolution.

Finally, we are faced with the enigma that Galileo failed to recognize the significant merit of Kepler in establishing the Copernican theory. What is worse, he completely ignored Kepler's work on the orbit of Mars. In this connection one wonders why "he refused to consider even for a moment the Tychonic variant as a third system"—although it was equally satisfactory for the observations at that time and was recognized, therefore, by Kepler himself as a natural transition to the Copernican view. Furthermore, Galileo stubbornly upheld his own false view of comets as optical atmospheric phenomena, despite Tycho Brahe's parallactic observations to the contrary. Most important of all is Galileo's failure to consider Tycho's observations as given in the Rudolphine Tables in 1627. De Santillana, however, dismisses Father Christoph Grienberger's comment that "it would have been better if he had produced more convincing proof of this theory before trying to adjust Scriptures to it" with the curt remark that "this was technically correct."

It should be recognized that Galileo is not behaving as a scientist per se in all his actions. His very title, upon which he insisted, was "Chief Philosopher and Mathematician to His Most Serene Highness." As a philosopher at court, he was bound to tangle with existing philosophies. His very pronouncements became politically and socially significant. It is not surprising, therefore, that his own clever attempt to outwit his opponents drew forth their worst as well as their best. In general, de Santillana praises Galileo's motives as worthy, presumably in view of the ultimate end to be achieved, and he castigates harshly the motives of all other people. It hardly seems that the case is so simply outlined in black and white. There are too many interconnecting threads.

De Santillana himself notes Galileo's primary concern "with the discovery of the telescope in 1610, which also established his name in the minds of the public at large as that of the leading scientist of his time." "This difficult lobbying Galileo implements with a social activity which would keep him, he hoped, in the limelight of the Roman world." It is understandable, therefore, that Galileo felt "he must bypass universities and address himself in the vernacular to the intelligent people at large." De Santillana concludes, "his real social strength lay in his extraordinary literary capacity, his brilliant repartee, his eloquence and charm, which gave him rank in a culture founded exclusively on belles-lettres and humanistic accomplishment." (Elsewhere he notes "Galileo was no modest man himself" and "his vanity was great.") With respect to the remarkable *Saggiatore*, he observes that "Galileo was again firmly established in the center of the literary scene." "Galileo is willing to pay that price to remain a man among men, a person and a force with his own culture." "It was a rational move and it would have obtained for Galileo all that he really wanted—the circulation of the Dialogue." With respect to Urban VIII we are even told "it looks as though he had been fooled successfully and in a legal-tight way."

This is hardly the place to reopen the case of Galileo, but personally I believe that *The Crime of Galileo*, with its emphasis upon the 1632 trial (about half the book) and upon the 1616 trial (about one-fourth the book), fails to take into account adequately the character and personality of Galileo throughout his whole life. As a man, Galileo deserves much praise, but he can also be blamed for a large part of the cumulative misunderstanding between him and his contemporaries. The reader is torn between regarding Galileo as a political churchman who had made Urban VIII appear "outwitted by Galileo" and as a religious devotee "esteeming obedience to be worth more than life." As for Galileo himself, one wonders if it can be justifiably said that "he gambled everything in speaking the truth unequivocally," in view of Galileo's own statement to the Inquisitor on 12 April 1633, "I have neither maintained nor defended in that book the opinion that the earth moves and the sun is stationary, but rather have shown opposite of the Copernican opinion and shown the arguments of Copernicus are weak and inconclusive." What did he really mean? Despite the author's defense, based largely on circumstantial evidence, I believe the answer lies in the enigma of Galileo's own personality.

There are some minor considerations about this book. One difficulty in reading the book is its failure to locate important personages like Colombe (even the index is not helpful here). One wonders how to interpret the remark "he dropped bodies from the Leaning Tower of Pisa with completely deceptive results," in view of L. Cooper's critical analysis. He censures P. Duhem for justifying the Church's conservatism from a positivistic point of view. Regardless of the chronological aspect of the question, Duhem's point still appears logically good. To speak of "Christendom, the communion of those who pray," is very indefinite and incomplete, to say the least. The unsuspecting reader might well be warned that the Copernican system of today is not the one advocated by Copernicus, as given in the author's helpful diagram.

It would be desirable in the case of a remark like "this last page is revealing" to find some reference. (In general the author uses Galileo's works by A. Favaro and merely introduces dates to identify items chronologically therein. In this particular instance, as in many others, he gives neither source nor date. It should be noted also that "the official texts are most of them from the English edition of Gebler.") Why does the author

translate the *Nuncius Siderus* as "The Message from the Stars," instead of the more customary "Starry (or Sidereal) Messenger"?

In view of the author's repeated reference to Riccardi's quoted statement, "The Jesuits will prosecute this with utmost bitterness," why did the author choose from three of his preliminary reviewers two particular persons whom he denotes with S.J. (incorrect in one case), and what did they really say? Why does he refer to F. Sherwood Taylor as "a Catholic historian"? It so happens that Taylor did become a Catholic *after* he wrote his book on *Galileo and the Freedom of Thought,* which is not even cited. In describing another person the author says, "he was a very Catholic historian, but a distinguished one." One wonders about his evidence for his belief in "an unmetaphysical universe like ours" in view of the many adherents to religion today. In short, it is difficult to disentangle the author's own philosophy from the problems he discusses.

In commendation, I would say that de Santillana's works are always delightful in their informative, relevant footnotes. He gives a particularly excellent description, moreover, of Aristotelian teleology. He clearly demonstrates technically that dogmatic thought, as in the case of the Church, is not manufactured overnight. In some notable instances the author renders impartial judgments regardless of "camp," as when he says "the sentence shows the hand of a competent jurist."

The very first words of the book, coupling "scientific endeavor and social authority," foretell what seems to be uppermost in the author's mind. He rightly regards "the Dialogue, this fateful work which was to become such a captain piece in Western history." He is greatly impressed with the idea that "the Galileo case itself looks like an inexplicable, tacit agreement between two warring factions."

In this spirit, accordingly, one finds throughout the book seemingly irrelevant references such as "an unknown and faintly absurd young cleric named Roger Williams was preparing his case against another minuscule and preposterous theocratic state." (Evidently the author wishes to regard the struggle for religious freedom as an analogous problem.) He further remarks "not innocent until proved guilty—the assumption not only in Rome, but also about 1630 in Boston." Elsewhere he states "an interesting parallel here with Governor Winthrop's problem in the case of Anne Hutchinson . . . to prove a criminal intention . . . it was less easy to do in Rome than in the somewhat high-handed Bay State Republic."

Such scintillating comments are stimulating but distractive. One always wonders about the correctness of the remark per se and then about its relevance to the present situation—for example, is it just an incidental opinion of the author? He seems to be generally worried about the "Reason of State . . . it led authorities in Rome to trump up charges against a scientist and indefatigably to persecute his memory for three centuries after his death . . . it led the Japanese to strike at Pearl Harbor." It is difficult to pinpoint de Santillana's criticism of modern events in the text in such remarks as "Caccini rides again among us and his name is legion." "We are very close, indeed, to inquisitional conditions without realizing it and without even the moral justification."

In the preface, however, the author reveals his personal conviction that "although the Oppenheimer case is very different from Galileo's as to content . . . the exact analogy in structure, in symptoms, and behavior shows that we are dealing with the same disease" . . . "policy decisions dictated by Reasons of State." He even goes so far as to try "to establish a one-to-one correspondence between the actors of the two dramas." In view of the fact that he has given neither analysis nor evidence for his conclusion about the Oppenheimer case, it is regrettable that he would even suggest that we "read" for certain individuals and groups of the past some of our contemporaries, particularly in view of some of the uninhibited opinions about the former. His added remark that "the ecclesiastical figures of the 17th century come out ahead of their modern counterparts" is hardly judicious. He still further confuses Galileo's case by casually suggesting Lavoisier's case as being even closer to the modern situation.

Suffice it to say that great human issues deserve more careful attention in a scholarly presentation. It seems to me that no correspondence has rigorously been established by de Santillana between the Oppenheimer case and the Galileo case—except the obvious fact that people as individuals and members of society are involved in both cases. The issues at stake are certainly different. The Galileo case involved the attitude of an established Church to a new philosophic point of view with respect to nature; in the Oppenheimer case we are dealing with the actions of an individual in a restricted society. At any rate, I believe that the inclusion of this modern extraneous, controversial material does not help to clarify the Galileo case, although the author would emphasize both in the preface and the index.

Closing this thoughtful book the reader may well find himself wondering how scientific endeavor then is related to social authority now, and what was really *The Crime of Galileo.*

RAYMOND J. SEEGER

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Management of Addictions. Edward Podolsky, Ed. Philosophical Library, New York, 1955. xvii + 413 pp. $7.50.

This book represents a style that is appearing more frequently of late, in which the editor selects a series of articles dealing with a particular subject, secures permission to reprint from the authors and from the magazines in which they have appeared, and then edits them in a single volume. This type of book has certain values and certain defects: although it commonly has a series of good articles by excellent authors, there is often a good deal of overlapping and certain points may not be covered at all.

This volume contains 26 articles on alcohol addiction and nine on drug addiction. There is a brief foreword by the editor, and the names of 48 contributors are listed. There is an acknowledgment to 19 different journals, expressing appreciation for permission to publish these articles, but nowhere is there a statement as to where or when each article appeared. Unless, therefore, the reader wishes to spend much time in research, he is ignorant of two facts that I feel should have been made available to him.

In general it can be said that the articles are of high grade and are excellent treatments of their subjects. It is difficult to pick out any particular chapters of the total of 35 for review and it is accordingly not easy to give any specific judgment of a volume of this type.

Chapter 1, "Psychodynamics in the excessive drinking of alcohol," by John W. Higgins, is a good general discussion of this whole problem. In the conclusions it is pointed out that, although there is no single factor that causes excessive drinking, one can search for the most significant ones. The author points out that "The depressant effect of the alcohol may simply reduce awareness of anxiety; or the act of drinking, together with the pharmacological action, can facilitate the expression of other previously inhibited psychic defense mechanisms . . . the nature of the anxiety being assuaged by drinking appears to vary from one drinker to another."

Chapter 2, by Charles J. Katz, and Chapter 3, by Giorgio Lolli, give rather specific directions about treating and managing the alcoholic and can be recommended as reading for anyone who is going to deal with such problems.

Chapters 4 and 5 summarize the stimulating ideas of Roger J. Williams and his colleagues concerning the genetotrophic concept of alcoholism, the question of nutritional deficiencies, and the marked differences in individuals as the basis for understanding alcoholism. This newer physiological approach to the whole problem has aroused much general interest. The essence of this theory is that individuals are born with their own special metabolic requirements, that some individuals need more of certain substances to keep in a well-nourished state, and that deficiencies, particularly of vitamins, produce a craving for alcohol. Work supporting this is quoted, showing that experimental feeding of animals can produce a craving or lack of craving for alcohol by withholding certain required substances in the diet or by giving ample supplies of them.

On this basis it is assumed that the alcoholic is born a potential alcoholic because of unusual requirements on his part or certain deficiencies in his metabolic capacities. Unless such an individual receives an excessive amount of these substances he will have the craving for alcohol. If the alcoholic is provided with plenty of these substances his craving disappears and he is able to control the use of alcohol. The few cases cited as evidence are hardly adequate to prove this theory, and the experience of a number of persons who have tried out this general theory and given large doses of vitamins in accordance with Williams' suggestions has not produced too convincing results. However, it remains a most intriguing theory and one that should receive a great deal of further study.

Several chapters deal with psychotherapy, endocrine treatment, the use of antabuse, and many nonsedative drugs, including the conditioned-reflex treatment.

Part II of the book deals with drug addiction. There are several chapters covering the general problem of drug addiction and some specific discussions of group psychotherapy, hospital treatment, endocrine treatment, prolonged sleep, and even electric-convulsive therapy. The final chapter, "The problem of narcotic drug addiction," by M. J. Pescor, is a good summary of the subject.

On the whole, this volume can be recommended, not only to the medical profession, but also to the more intelligent nonmedical persons interested in this problem, as a series of well-written articles by well-qualified writers, discussing many phases of the problems of alcohol and drug addiction.

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Practical Horticulture. James S. Shoemaker and Benjamin J. E. Teskey. Wiley, New York; Chapman & Hall, London, 1955. vi + 374 pp. Illus. $4.20.

To cover adequately in one volume of 370 pages the entire field of horticulture, from the principles of landscape design to the commercial production of onions, might appear to be an impossible task. However, the new book, *Practical Horticulture*, in the Wiley Farm Series successfully presents all phases of the subject whether the interest is in ornamentals such as lawns, flowers or trees; in vegetables of most commercial varieties; in bush or tree fruits; or even in house plants.

The authors, Shoemaker and Teskey, have eliminated all the chaff, presenting only the pertinent facts of site, variety, fertilizing, culture, harvest, and storage of the various crops studied. These are not simply empirical ideas borrowed from previous textbooks but the very latest findings of research and experimental stations, much of which is not general knowledge as yet. Since the chapters are necessarily concise, at the conclusion of each a list of references for additional study is presented for the student who wishes to delve further into the subject.

From the point of view of the student, the arrangement of the material should facilitate his grasp of the subject, since every phase of the topic under discussion is grouped in one chapter. It is not necessary to refer to other parts of the book for a discussion on propagation, fertilization, or insect control, for instance, because the specific information on a crop is gathered together and presented as a package that will form a well-rounded picture in the student's mind. As he works his way through the chapters, the repetition of these facts in various forms should enable him to retain them more easily. The concise "nothing-but-the-facts" presentation should also appeal to the modern student

who appears to have little patience with long-winded discussions, however important.

The textbook will probably prove more valuable to the instructor who is presenting the commercial aspects of fruits and vegetables to his students, since the bulk of the book is concerned with these matters. However, the first 125 pages could serve well as the basis for a general introductory course in ornamental horticulture, acquainting the student with the potentials of the subject and encouraging him to further study and specialization.

Although a considerable part of the book would probably not have too much appeal to the average home gardener, for whom it was not apparently intended, I think there is still sufficient information in the balance of the book to merit its purchase as a guide to more attractive and productive home grounds. It is a notable addition to the Wiley Farm Series.

GERALD V. S. RAYNOR

Huntington, New York

Patent Law in the Research Laboratory. John Kenneth Wise. Pilot Books, No. 4. Reinhold, New York; Chapman & Hall, London, 1955. 145 pp. $2.95.

There has existed a need for a simple, straightforward, very short book such as this (140 small pages of text) giving a general introduction to patent law. That need is on the whole fairly well met by Wise's book. Its title, however, is a misnomer, for it is no more specific to the research laboratory than most patent law books. The typographic errors scattered throughout seem unnecessary.

Wise's history of the patent system is the best brief statement of it that I have seen. After that he wisely builds his text around verbatim reproductions of the key sections of the statutes and the Patent Office Rules of Practice. To a limited extent he illustrates by citing court decisions. He cites 27 cases; the next shortest such book cites 120. Such oversimplification can be misleading and even erroneous. For example, he quotes two cases and says: "These two illustrations will suffice to show, generally, what is required to prove reduction to practice." They do not suffice, and I doubt that any such short discussion could suffice.

Generally then, this is a good introductory book, provided that one reads further before believing that one has more than the most general understanding of the patenting of inventions. This being the case, it is regrettable that no bibliography for further reading is given. Wise should at least have listed *Patent Notes for Engineers* by Tuska (1954 ed.), *Patent Fundamentals* by Amdur (1948 ed.), *Patent Law* by Biesterfeld (1949 ed.), *Patent Tactics and Law* by Hoar (1950 ed.), *Patent Practice and Management* by Calvert (1950) and have mentioned the most definitive: the 4-volume *Walker on Patents* (Deller ed., 1937, with 1-volume 1954 supplement).

H. GORDON DYKE

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Island Bibliographies. Marie-Hélène Sachet and F. Raymond Fosberg, Pacific Science Board of the National Academy of Sciences–National Research Council, Washington, D.C., 1955. v + 577 pp. $6.

This most useful reference work is in reality three bibliographies, each dealing separately with Micronesian botany, coral atolls, and the vegetation of tropical Pacific islands. Each is complete with a subject index and an addendum. A single reference list of serial abbreviations serves for all three. These bibliographies are designed for maximum usefulness to investigators, of which there are now many in the Pacific area, in finding the literature on their particular subjects. For this purpose each entry bears an exceptionally well-prepared annotation, including, for separate books, Library of Congress or other library call numbers. Call numbers are also given in the serial reference list. The authors have emphasized extent of coverage of the literature and verification and accuracy of citations. The original works actually have been seen whenever possible.

The first of these three is an "Annotated bibliography of Micronesian botany," covering the Marianas, Caroline, Marshall, and Gilbert archipelagos with the isolated islands of Marcus, Wake, Mapia, Nauru, and Ocean. Much Japanese literature is listed with translated titles when needed. The coverage is broad, as is shown by the index headings, geographic, systematic, floristic, ecologic, geologic, climatic, economic, and so forth.

The second is a "Bibliography of the land ecology and environment of coral atolls," these being so broadly defined as to be nearly synonymous with "low islands." They are found mainly in the central and western Pacific but also in the Indian Ocean, the Gulf of Mexico, and the Caribbean Sea with Rocas Island in the Atlantic off Brazil and Clipperton Island in the western Pacific. Everything above high tide line is dealt with—geography, geology, climate, hydrobiology, soils, and the material culture side of ethnology as well as more orthodox natural history. The coverage is extensive but not exhaustive.

The third is a "Selected bibliography of vegetation of the tropical Pacific islands," the term *vegetation* being used in the proper sense of plant cover rather than floristic composition. The area covered extends from the eastern Pacific to the Bonins, Palau, the Admiralties, Bismarck Archipelago, and the islands of the Coral Sea. New Zealand, Lord Howe and Norfolk Islands, Australia, the East Indies, the Philippines, Formosa, the Ryukyus, Japan, and Juan Fernández are excluded. Few writers on this area have been vegetation-conscious, but since a knowledge of this important geographic feature is of such significance in geography, geology, ecology, zoology, climatology, soil science, forestry, agriculture, economics, military science, and engineering, the authors have sought out and listed all worth-while vegetation literature that they could find. The index, arranged by islands and island groups alone, reveals vividly how little is known of this important feature and how much further investigation is needed.

As the volume of our published literature increases,

bibliographies as tools of science become of greater importance. In publishing these three valuable bibliographies the National Academy of Sciences–National Research Council is carrying out its duty "to stimulate research in pure and applied science." The authors' emphasis on the usefulness to investigators, especially in such features as ample annotations, precise dates of publication, library call numbers, sources of information, cross references, evaluation, and references to available translations, will be deeply appreciated.

Users, however, may sometimes be handicapped by the authors' failure to observe some rules of bibliographic procedure that have been evolved to meet their needs. Dates placed at the beginning of the citation both mark off the entries and enable readers to find readily the items referred to in the subject index by author and date. In this work, however, the dates appear only at the ends of the citations. In this day of emphasis on illustrations these should always be designated, at least by *illus.* or *illustr.* in citing articles with pictures. When, in searching for material of a given nature, one is compelled to look back from the index to the main text of the bibliography 150 times under a single heading, one feels that the indexer should have introduced subheadings. In addition, a brief word or two in parentheses after each author-date reference in the subject index would have been a great gain to the user.

This and some other losses are scarcely offset in my opinion by the authors' plea that the time spent in pursuing the niceties of bibliographic technique can better be spent in extending its coverage. Are the organizations on which rests the obligation to provide the tools of science so hard pressed that they cannot also provide for their polished presentation? Alas, the answer is frequently in the affirmative, for bibliographic work is too often an orphaned occupation, disowned by the research organizations that it serves, and willing authors must squeeze the time for preparing bibliographies from that budgeted for research—or from their needed rest.

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Hungry Generations. The nineteenth-century case against Malthusianism. Harold Boner. King's Crown Press, Columbia University, New York, 1955. viii + 234 pp. $3.75.

Although the author promises nothing more than to state "The nineteenth-century case against Malthus," the reader may put aside his book with a feeling of great disappointment. This is the author's fault only to the extent that he holds too closely to the opinions of a few well-known and many obscure economists, politicians, and writers in 19th-century England who had something to say for or against Malthus. He quotes them extensively but does not give the reader a clear idea of the rise and fall of Malthusianism and its impact on English society. Instead of stating succinctly what Malthusianism is and exposing the glaring, though cleverly hidden deficiencies of his double-barreled theory of misery and despair, the author dwells pedantically on the numerous hairsplitting, metaphysical, and theological controversies between Malthus' followers and opponents, which mean so little to us today, when the case for or against Malthus is being argued on a more scientific basis with the help of census data, vital statistics, population theory, and modern agricultural, nutritional, and biochemical concepts of human needs and resources.

In spite of the author's narrow approach to a fundamental problem of human destiny, the faithful reader of his book will be rewarded with a better understanding of the psychological aspects of British reaction to the hammer blows of Malthus' theory. He will learn why, in the tense and emotional atmosphere of the Malthus controversy, only a few cool minds realized that, at the time of Malthus, there was plenty of untilled land in England capable of intensive cultivation and that although, as Malthus stated, man is capable of increasing his number in a geometric ratio, this is not necessarily the case.

FRANCIS JOSEPH WEISS
Managua, Nicaragua

Laboratory Studies in Biology: Observations and Their Implications. Chester Lawson, Ralph Lewis, Mary Alice Burmester, and Garrett Hardin. Freeman, San Francisco, 1955. vii + 328 pp. Illus. $3.50.

This manual covers practically the whole gamut of biology, starting from the use of the microscope, and ending with the study of cells and population problems. En route, it deals with the anatomy and physiology of the different systems of the body, genetics, growth and differentiation, paleontology, taxonomy, evolution, and the various plants and animals.

Introducing Sea Shells. R. Tucker Abbott. Van Nostrand, New York–London, 1955. vi + 64 pp. Illus. + plates. Paper, $2.50.

Subtitled "a colorful guide for the beginning collector," this pamphlet, built around a selection of color plates from the author's *American Seashells*, is an interesting introduction to those mollusks that produce shells. Although thus limited in scope, the emphasis is nevertheless upon the living mollusk rather than upon its dead shell. There are chapters on how and where to look for shells, how to prepare a collection, and a list of dealers in shells. It is difficult, however, to understand the publishers' reason for asking $2.50 for this brochure, as good as it is, when it would seem that they should be able to sell two or three times as many for $1. It looks as if the dollar, like the nickel before it, is on the way out as a standard for certain items.

JOEL W. HEDGPETH
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New Books

"Krebiozen," the Great Cancer Mystery. George D. Stoddard. Beacon Press, Boston, 1955. 282 pp. $3.50.

Encyclopedia of Chemical Technology. vol. 14, *Thermodynamics to Waterproofing.* Raymond E. Kirk and Donald F. Othmer, Eds. Interscience Encyclopedia, New York, 1955. 980 pp. $30, single copy; $25, subscription.

Frontiers of Astronomy. Fred Hoyle. Harper, New York, 1955. 360 pp. $5.

The Diseases of Occupations. Donald Hunter. Little, Brown, Boston, 1955. 1046 pp. $20.

Building Planning and Design Standards. For architects, engineers, designers, consultants, building committees, draftsmen and students. Harold R. Sleeper, Wiley, New York; Chapman & Hall, London, 1955. $12.

The Quantitative Analysis of Drugs. D. C. Garratt. Philosophical Library, New York, rev. ed. 2, 1955. 670 pp. $17.50.

A Short History of Medicine. Erwin H. Ackerknecht. Ronald Press, New York, 1955. 258 pp. $4.50.

One in Six. An outline of the cancer problem. I. Hieger. Wingate, London, 1955. 80 pp. 12s. 6d.

Classical Electricity and Magnetism. Wolfgang K. Panofsky and Melba Phillips. Addison-Wesley, Cambridge 42, Mass., 1955. 400 pp. $8.50.

The Unified System Concept of Nature. Stephen Th. Bornemisza. Vantage, New York, 1955. 137 pp. $3.

Analytic Geometry. Frederick H. Steen and Donald H. Ballou. Ginn, Boston 17, Mass., ed. 3, 1955. 225 pp. $3.50.

Plastics for Corrosion-Resistant Applications. Raymond B. Seymour and Robert H. Steiner. Reinhold, New York, 1955. 423 pp. $7.50.

The Biology of the Spirit. Edmund W. Sinnott. Viking, New York, 1955. 180 pp. $3.50.

Genetics is Easy. A handbook of information. Philip Goldstein. Lantern Press, New York 10, ed. 2, 1955. 238 pp. $4.

The Only Way Out. Jacob Rosin. American Press, New York, 1955. 114 pp. $2.95.

The Case History of Sigmund Freud. A psychobiography. Maurice Natenberg. Regent House, Chicago, 1955. 245 pp. $3.95.

Yearbook of Anthropology, 1955. vol. 1. William L. Thomas, Jr., Ed. Wenner-Gren Foundation for Anthropological Research, New York, 1955. 836 pp.

Forestry Handbook. Reginald D. Forbes, Ed. Ronald Press, New York, 1955. 1200 pp. $15.

A History of Philosophy. B. A. G. Fuller. Revised by Sterling M. McMurrin. Holt, New York, ed. 3, 1955. 618 pp. $6.90.

The Extra Pharmacopoeia. vol. 2. Pharmaceutical Press, London, ed. 23, 1955. 1501 pp. £2 17s. 6d.

Imagination's Other Place. Poems of science and mathematics. Compiled by Helen Plotz. Crowell, New York, 1955. 200 pp. $3.50.

Hawley's Technical Speller. Compiled by Gessner G. Hawley and Alice W. Hawley. Reinhold, New York; Chapman & Hall, London, 1955. 146 pp. $2.95.

The Permanent Revolution in Science. Richard L. Schanck. Philosophical Library, New York, 1954. 112 pp. $3.

My Hobby Is Collecting Rocks and Minerals. David E. Jensen. Hart, New York, 1955. 122 pp. $2.95.

Glossary of Selected Geologic Terms. With special reference to their use in engineering. Colorado Scientific Society Proceedings, vol. 16. The Society, Denver, 1955. 165 pp. Paper, $2.75; cloth, $3.50.

Science and the Course of History. Pascual Jordan. Trans. by Ralph Manheim. Yale Univ. Press, New Haven, Conn.; Oxford Univ. Press, London, 1955. 139 pp. $2.50.

World Economic Geography with Emphasis on Principles. Earl B. Shaw. Wiley, New York; Chapman & Hall, London, 1955. 582 pp. $6.50.

The Contriving Brain and the Skillful Hand in the United States. Something about history and philosophy of history. James C. Malin. The author, Lawrence, Kan., 1955. 436 pp. $3.50.

Problems and Control of Air Pollution. Proceedings of the First International Congress on Air Pollution held in New York City, 1–2 Mar. 1955, under the sponsorship of the Committee on Air-Pollution Controls of the American Society of Mechanical Engineers. Frederick S. Mallette, Ed. Reinhold, New York; Chapman & Hall, London, 1955. 272 pp. $7.50.

Annual Review of Physical Chemistry. vol. 6. G. K. Rollefson, Ed. Annual Reviews, Stanford, Calif., 1955. 515 pp. $7.

The Physiology of Diapause in Arthropods. Cambridge Monogr. in Experimental Biology No. 4. A. D. Lees. Cambridge Univ. Press, New York, 1955. 151 pp. $2.50.

Handbook of Hydrocarbons. S. W. Ferris. Academic Press, New York, 1955. 324 pp. $8.50.

Handbuch der Pflanzen-Züchtung. Band 1, *Grundlagen der Züchtung.* Lieferung 1, *Biologisch-genetisch und Physiologische Grundlagen der Zuchtung.* Hans Kappert and Wilhelm Rudorf, Eds. Paul Parey, Berlin, ed. 2, 1955 (to be published in 6 vols., comprising approximately 38 issues). DM. 13.50 per issue.

The Construction of Laboratory Apparatus for Schools. Workshop designs with specifications and instructions. Ser. II. *Secondary* (in French and English). Prepared for UNESCO by H. Struers Chemiske Laboratorium, Copenhagen, Denmark. UNESCO, Paris, 1955 (order from Columbia Univ. Press, New York). Portfolio and 76 plates. $8.

Erlebtes aus der Thoraxchirurgie. Rudolf Nissen. Thieme, Stuttgart, 1955 (order from Intercontinental Medical Books Corp., New York). 65 pp. $3.40.

Amateur Astronomer's Handbook. J. B. Sidgwick. Macmillan, New York, 1955. 580 pp. $12.50.

Advances in Cancer Research. vol. III. Jesse P. Greenstein and Alexander Haddow. Academic Press, New York, 1955. 369 pp. $8.50.

Cancer Cells. E. V. Cowdry. Saunders, Philadelphia, Pa., 1955. 677 pp. $16.

Gas Kinetics. An introduction to the kinetics of homogeneous gas reactions. A. F. Trotman-Dickenson. Academic Press, New York; Butterworths, London. 1955. 322 pp. $8.

Instruments for Measurement and Control. Werner G. Holzbock. Reinhold, New York; Chapman & Hall, London, 1955. 371 pp. $10.

Man's Nature and Nature's Man. The ecology of human communities. Lee R. Dice. Univ. of Michigan Press, Ann Arbor, 1955. 329 pp. $5.

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ASSOCIATION AFFAIRS

Traveling High-School Science Libraries

The AAAS Traveling High-School Science Library Program, made possible by a grant from the National Science Foundation, began operation in October when the first unit of the libraries arrived at each of the 66 high schools selected for the experiment. Announcements of the program and its objectives were made in *The Scientific Monthly* [**81,** 159 (Sept. 1955)] and in *Science* [122, 190 (29 July 1955)]. The program was organized with assistance from the U.S. Office of Education and the National Education Association and its affiliated organizations.

The general purposes of the project are to stimulate interest in reading science books, to broaden the science background of high-school students, and to assist students with scientific interests in choosing a career.

The books, which number 150, are divided into six units of 25, each fitted into an attractive case that serves both for display in the school libraries and for shipping the books from school to school. Each school retains a unit for 4 to 5 weeks while classes are in session; thus, by 15 May 1956, all six units will have been used by the students and teachers at the 66 schools.

The 150 books were selected with the assistance of more than 250 scientists, science teachers, and librarians from a long preliminary list that was compiled from various sources. The 150 volumes are included in each of the 12 libraries; 11 libraries are circulating to schools and one is being used for display at meetings of national organizations. Most of the books can be read and understood by anyone with a limited knowledge of mathematics and little or no science background. A very few books may constitute a challenge to the superior high-school student.

As previously mentioned, the program is experimental. A portion of the experiment will be an evaluation of the popularity and suitability of the books for general high-school reading; the evaluation will be based, in part, on a study of the actual circulation records at the 66 schools. There are already indications that some important books were not included and that a few of the books chosen may have been poor selections. These mistakes are regretted and are due to the short time available (July to October) in which to organize the program and place it in operation.

The matter of recommendintg a list of science books suitable for acquisition by all high-school libraries will continue to be studied by the AAAS during the operation of the traveling library program. The publication of such a recommended list is envisioned as a future undertaking in which the cooperation of all interested persons and organizations is solicited.

The list of books in the libraries follows.

Books in the Libraries

Alter, D., and C. H. Cleminshaw. *Pictorial Astronomy.* Crowell, 1952.

Andrews, R. C. *Beyond Adventure: The Lives of Three Explorers.* Duell, Sloan and Pearce, 1954.

Andrews, R. C. *This Amazing Planet.* Putnam's, 1940.

Armitage, A. *Sun, Stand Thou Still: The Life and Work of Copernicus the Astronomer.* Schuman, 1947.

Baitsell, G. A. (Ed.) *Science in Progress.* Yale Univ. 1st ser., 1939; 4th ser., 1945; 5th ser., 1947; 6th ser., 1949; 7th ser., 1951; 8th ser., 1953.

Bakst, A. *Mathematics: Its Magic and Mastery.* Van Nostrand, 1952.

Ball, M. W. *This Fascinating Oil Business.* Bobbs-Merrill, 1940.

Bates, M. *The Nature of Natural History.* Scribner's, 1954.

Bates, M. *The Prevalence of People.* Scribner's, 1955.

Beebe, W. *Half Mile Down.* Duell, Sloan and Pearce, 1951.

Benedict, R. *The Chrysanthemum and the Sword.* Houghton Mifflin, 1946.

Berrill, N. J. *Journey into Wonder.* Dodd, Mead, 1952.

Berrill, N. J. *Sex and the Nature of Things.* Dodd, Mead, 1953.

Borek, E. *Man, the Chemical Machine.* Columbia Univ., 1952.

Bremner, M. D. K. *The Story of Dentistry.* Dental Items of Interest, 1954.

Brinton, C. *Ideas and Men: The Story of Western Thought.* Prentice-Hall, 1950.

Bronowski, J. *The Common Sense of Science.* Harvard Univ., 1955.

Buchsbaum, R. M. *Animals without Backbones.* Univ. of Chicago, 1948.

Burnet, Sir M. *Natural History of Infectious Disease.* Cambridge Univ., 1953.

Carlson, A. J., and V. Johnson. *The Machinery of the Body.* Univ. of Chicago, 1953.

Carson, R. *The Sea Around Us.* Oxford Univ., 1951.

Ceram, C. W. *Gods, Graves, and Scholars: The Story of Archaeology.* Knopf, 1954.

Christensen, C. M. *The Molds and Man.* Univ. of Minnesota, 1951.

Clapesattle, H. *The Doctors Mayo.* Univ. of. Minnesota, 1954.

Cohen, I. B. *Science, Servant of Man.* Little, Brown, 1948.

Collis, J. S. *The Triumph of the Tree.* Sloane, 1954.

Cooley, D. G. *The Science Book of Wonder Drugs.* Franklin Watts, 1954.

Coombs, C. *Skyrocketing into the Unknown.* Morrow, 1954.

Courant, R., and H. Robbins. *What is Mathematics?* Oxford Univ., 1941.

Crombie, A. C. *Augustine to Galileo: The History of Science A.D. 400–1650.* Harvard Univ., 1953.

Croneis, C., and W. C. Krumbein. *Down to Earth: An Introduction to Geology.* Univ. of Chicago, 1936.

Curie, E. *Madame Curie.* Doubleday, 1953.

Dampier, Sir W. *A History of Science and its Relations with Philosophy and Religion.* Cambridge Univ., 1952.

Dantzig, T. *Number: The Language of Science.* Macmillan, 1954.

Darwin, C. *The Voyage of the Beagle.* Dutton, 1906.

Dean, G. *Report on the Atom.* Knopf, 1954.

de Kruif, P. *Microbe Hunters.* Harcourt, Brace, 1932.

Desch, H. E. *Timber: Its Structure and Properties.* St. Martin's, 1953.

Diebold, J. *Automation: The Advent of the Automatic Factory.* Van Nostrand, 1952.

Ditmars, R. L. *Reptiles of the World.* Macmillan, 1955.

Douglas, J. S. *The Story of the Oceans.* Dodd, Mead, 1952.

Dubos, R. J. *Louis Pasteur: Free Lance of Science.* Little, Brown, 1950.

Dubos, R., and J. Dubos. *The White Plague: Tuberculosis, Man and Society.* Little, Brown, 1952.

Eaton, J. R. *Beginning Electricity.* Macmillan, 1952.

Eddington, A. S. *The Nature of the Physical World.* Cambridge Univ., 1953.

Fairchild, D. *The World Was My Garden.* Scribner's, 1954.

Farber, E. *The Evolution of Chemistry.* Ronald, 1952.

Faxon, N. W. (Ed.) *The Hospital in Contemporary Life.* Harvard Univ., 1949.

Fenton, C. L., and M. A. Fenton. *Giants of Geology.* Doubleday, 1952.

Finch, J. K. *Engineering and Western Civilization.* McGraw-Hill, 1951.

Fleming, D. *William H. Welch and the Rise of Modern Medicine.* Little, Brown, 1954.

Fox, R. *Great Men of Medicine.* Random House, 1947.

Fox, R. *Milestones of Medicine.* Random House, 1950.

Friend, J. N. *Man and the Chemical Elements.* Scribner's, 1953.

Friend, J. N. *Numbers: Fun and Facts.* Scribner's, 1954.

Gabrielson, I. N. *Wildlife Conservation.* Macmillan, 1952.

Gamow, G. *Mr Tompkins Explores the Atom.* Cambridge Univ., 1955.

Gamow, G. *Mr Tompkins in Wonderland.* Cambridge Univ., 1953.

Gamow, G. *One, Two, Three . . . Infinity.* Viking, 1954.

Gamow, G. *The Moon.* Schuman, 1953.

Garrett, H. E. *Great Experiments in Psychology.* Appleton-Century-Crofts, 1951.

Gibberd, F. *Town Design.* Reinhold, 1953.

Glasstone, S. *Sourcebook on Atomic Energy.* Van Nostrand, 1950.

Grabbe, P. *We Call It Human Nature.* Harper, 1939.

Gray, J. *How Animals Move.* Cambridge Univ., 1953.

Grinter, L. E., H. N. Holmes, *et al. Engineering Preview.* Macmillan, 1947.

Haggard, H. W. *Devils, Drugs, and Doctors.* Harper, 1929.

Hamilton, W. J., Jr. *American Mammals: Their Lives, Habits and Economic Relations.* McGraw-Hill, 1939.

Harrow, B. *Casimir Funk: Pioneer in Vitamins and Hormones.* Dodd, Mead, 1955.

Hegner, R. *Parade of the Animal Kingdom.* Macmillan, 1955.

Heyerdahl, T. *Kon-Tiki: Across the Pacific by Raft.* Rand McNally, 1950.

Hodgman, C. C., R. C. Weast, *et al. Handbook of Chemistry and Physics.* Chemical Rubber, 1954.

Hogben, L. *Mathematics for the Million.* Norton, 1951.

Hogben, L. *Science for the Citizen.* Norton.

Holland, R., Jr. *The Physical Nature of Flight.* Norton, 1951.

Hooton, E. A. *Up From the Ape.* Macmillan, 1946.

Jaffe, B. *Crucibles: The Story of Chemistry.* Simon and Schuster, 1951.

Jaffe, B. *Men of Science in America.* Simon and Schuster, 1946.

Kaempffert, W. *Explorations in Science.* Viking, 1953.

Kaufert, F. H., and W. H. Cummings. *Forestry and Related Research.* Soc. of American Foresters, 1955.

Kellogg, C. E. *The Soils That Support Us.* Macmillan, 1951.

Kendall, J. *Great Discoveries by Young Chemists.* Crowell, 1953.

Killeffer, D. H. *The Genius of Industrial Research.* Reinhold, 1948.

King, T. *Water: Miracle of Nature.* Macmillan, 1955.

Kraus, E. H., and C. B. Slawson. *Gems and Gem Materials.* McGraw-Hill, 1947.

Kugelmass, J. A. *J. Robert Oppenheimer and the Atomic Story.* Messner, 1953.

Laird, C., and R. Laird. *Weathercasting.* Prentice-Hall, 1955.

Lavine, S. A. *Steinmetz: Maker of Lightning.* Dodd, Mead, 1955.

Levinger, E. E. *Albert Einstein.* Messner, 1949.

Levinger, E. E. *Galileo: First Observer of Marvelous Things.* Messner, 1954.

Lieber, L. R. *The Education of T. C. Mits.* Norton, 1944.

Logsdon, M. I. *A Mathematician Explains.* Univ. of Chicago, 1947.

Lull, R. S. *Organic Evolution.* Macmillan, 1945.

MacCurdy, E. (Ed. and Tr.) *The Notebooks of Leonardo da Vinci.* Braziller, 1955.

Macgowan, K. *Early Man in the New World.* Macmillan, 1953.

Macmillan, M. *Green Seas and White Ice.* Dodd, Mead, 1948.

Menzel, D. H. *Our Sun.* Blakiston, 1950.

Morris, L., and K. Smith. *Ceiling Unlimited: The Story of American Aviation from Kitty Hawk to Supersonics.* Macmillan, 1953.

Moulton, F. R., and J. J. Schifferes. *The Autobiography of Science.* Doubleday, 1953.

Munn, N. L. *The Evolution and Growth of Human Behavior.* Houghton Mifflin, 1955.

Murchie, G., Jr. *Song of the Sky.* Houghton Mifflin, 1954.

Nakaya, U. *Snow Crystals, Natural and Artificial.* Harvard Univ., 1954.

Norman, J. R. *A History of Fishes.* A. A. Wyn, 1948.

Oehser, P. H. *Sons of Science: The Story of the Smithsonian Institution and its Leaders.* Schuman, 1949.

Payne-Gaposchkin, C. *Stars in the Making.* Harvard, 1952.

Peattie, D. C. *Flowering Earth.* Putnam's, 1939.

Reid, C. *From Zero to Infinity.* Crowell, 1955.

Riegel, E. R. *Industrial Chemistry.* Reinhold, 1949.

Robinson, M. L. *Runner of the Mountain Tops: The Life of Louis Agassiz.* Random House, 1939.

Roe, A. *The Making of a Scientist.* Dodd, Mead, 1953.

Rogers, B. A. *The Nature of Metals.* Iowa State Coll., 1951.

Roueche, B. *Eleven Blue Men, and Other Narratives of Medical Detection.* Little, Brown, 1954.

Schück, H., R. Sohlman, *et al. Nobel: The Man and His Prizes.* Univ. of Oklahoma, 1951.

Seton, E. T. *Trail of an Artist Naturalist.* Scribner's, 1948.

Shapley, H. (Ed.) *Climatic Change: Evidence, Causes, and Effects.* Harvard Univ., 1953.

Shapley, H., S. Rapport, and H. Wright. *A Treasury of Science.* Harper, 1954.

Shaw, Sir N. *The Drama of Weather.* Cambridge Univ., 1940.

Silverman, M. *Magic in a Bottle.* Macmillan, 1953.

Simpson, G. G. *Life of the Past: An Introduction to Paleontology.* Yale Univ., 1953.

Singer, C. *A History of Biology.* Schuman, 1951.

Slaughter, F. G. *Immortal Magyar: Semmelweis, Conqueror of Childbed Fever.* Schuman, 1950.

Sloop, M. T. M. *Miracle in the Hills.* McGraw-Hill, 1953.

Smart, W. M. *The Origin of the Earth.* Cambridge Univ., 1953.

Smith, F. G. W., and H. Chapin. *The Sun, the Sea and Tomorrow.* Scribner's, 1954.

Sootin, H. *Isaac Newton.* Messner, 1955.

Sootin, H. *Michael Faraday: From Errand Boy to Master Physicist.* Messner, 1954.

Spencer, S. M. *Wonders of Modern Medicine.* McGraw-Hill, 1953.

Sproul, E. E. *The Science Book of the Human Body.* Franklin Watts, 1955.

Storck, J., and W. D. Teague. *Flour for Man's Bread: A History of Milling.* Univ. of Minnesota, 1952.

Sullivan, J. W. W. *The Story of Metals.* Iowa State Coll., 1951.

Taylor, F. S. *A Short History of Science and Scientific Thought.* Norton, 1949.

Teale, E. W. *Grassroot Jungles: A Book of Insects.* Dodd, Mead, 1950.

Teale, E. W. *North with the Spring.* Dodd, Mead, 1951.

Teale, E. W. (Ed.) *The Insect World of J. Henri Fabre.* Dodd, Mead, 1950.

Tunnard, C., and H. H. Reed. *American Skyline.* Houghton Mifflin, 1955.

U.S. Dept. of Agriculture. *Insects: The Yearbook of Agriculture.* U.S. Govt. Printing Office, 1952.

U.S. Dept. of Agriculture. *Plant Diseases: The Yearbook of Agriculture.* U.S. Govt. Printing Office, 1953.

U.S. Dept. of Agriculture. *Trees: The Yearbook of Agriculture.* U.S. Govt. Printing Office, 1949.

von Frisch, K. *The Dancing Bees.* Harcourt, Brace, 1955.

Walker, K. *The Story of Medicine.* Oxford Univ., 1955.

Wallace, G. J. *An Introduction to Ornithology.* Macmillan, 1955.

White, A. T. *Lost Worlds: The Romance of Archaeology.* Random House, 1941.

Williams, B., and S. Epstein. *William Crawford Gorgas: Tropic Fever Fighter.* Messner, 1953.

Woodham-Smith, C. *Lonely Crusader: The Life of Florence Nightingale.* McGraw-Hill, 1951.

Zinsser, H. *Rats, Lice and History: A Study in Biography.* Little, Brown, 1935.

Schools in the Program

The greatest apparent need for the science books of the traveling libraries is in the smaller high schools located in communities with poor library facilities. Therefore the participating schools were chosen from those with an enrollment of approximately 200 to 350 students in the ninth to 12th grades, inclusive. The schools were selected from recommendations of state departments of education and members of college and university faculties in a given area who had a knowledge of the high schools and of their library and science-teaching facilities. Each school so recommended was informed of the program and its objectives and was invited to indicate its interest in becoming a part of the program. From the replies received, 66 schools representing a diversity of local socioeconomic conditions and a wide geographic distribution were selected. The list of schools follows.

California: Davis Joint Union High School; Live Oak Union High School; Patterson Union High School; Strathmore Union High School; Sutter Union High School; Weed High School.

Georgia: Cuthbert High School; Fort Valley High School; Manchester High School; Nahunta High School; Ocilla High and Industrial School; Quitman High School.

Indiana: Delphi-Deercreek Township Consolidated School, Delphi; Mooresville High School; Morgan Township School, Valparaiso; Morocco High School; Northwestern High School, Kokomo; Pendleton High School.

Kansas: Atchison County Community High School, Effingham; Buhler Rural High School; Caney High School; Grant County Rural High School, Ulysses; Kingman High School; Neodesha High School.

Kentucky: Campbellsville High School; Harrodsburg High School; Richmond High School; Rosenwald High School, Harlan; Shepherdsville High School; Wolfe County High School, Campton.

Massachusetts: Weston High School; Ipswich High School.

Nebraska: Blair High School; Crete High School; Gordon High School; Ogallala High School; Superior High School; Valentine High School.

New York: Bemus Point High School; Canajoharie Central School; Cassadaga Valley Central School, Sinclairville; Geneseo Central School.

Oregon: Creswell Union High School; Elmira Union High School; Estacada Union High School; Oakridge High School; Rainier Union High School; Stayton Union High School.

South Dakota: Custer High School; Gregory High School; Central High School, Madison; Sisseton High School; Webster High School; Winner Public Schools.

Tennessee: Alcoa High School; Castle Heights Military Academy, Lebanon; Catholic High School for Boys, Memphis; Ducktown High School; Norris High School; Powell Valley High School, Speedwell.

Wisconsin: Adams-Friendship High School, Adams; Brodhead High School; Central High School, Salem; Hudson High School; Markesan High School; Phillips High School.

Comments and Suggestions Are Invited

The AAAS requests interested persons to submit their comments and suggestions concerning the Traveling High-School Science Library Program in general, to offer their personal evaluations of any books in the list, and to suggest appropriate books currently in print which they would recommend as substitutes or additions. Such observations will assist in perfecting the proposed book list that was mentioned previously and in making substitutions of books in the libraries if means should become available for continuing the program beyond the present school year.

HILARY J. DEASON

MISSILE SYSTEMS

SCIENTISTS

Typical areas of interest include:

Neutron and reactor physics; general electronics and radar; applied mathematics; systems analysis of guidance and controls; integration of ballistic type missiles with vertical guidance; upper atmosphere electromagnetic properties; RF propagation in microwaves; experimental laboratory instrumentation.

Inquiries are invited.

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by AUGUST PI SUNER

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Charles M. Stern

This *Survey of the Study of Life*, told by one of the foremost living biologists, illuminates the high-points of progress in this science by fascinating glimpses into philosophical theories throughout the ages until reaching our present-day observational methods.

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The author is a former President of the Academy of Medicine in Barcelona.

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(*Continued from page 50*)

Silicic Science. A review of the colloid scientific properties and phenomena exhibited by matter composed essentially of the element silicon. Ernst H. Hauser. Van Nostrand, New York, 1955. 188 pp. $5.

Man's Emerging Mind. Man's progress through time—trees, ice, flood, atoms and the universe. N. J. Berrill. Dodd, Mead, New York, 1955. 308 pp. $4.

Progress in the Chemistry of Organic Natural Products. vol. XII. L. Zechmeister, Ed. Springer, Vienna, Austria, 1955. 550 pp. $19.80.

Comprehensive Inorganic Chemistry. vol. 4. pt. I, *Zinc, Cadmium, and Mercury*. Howard M. Cyr and editors; pt. II, *Scandium, Yttrium, and the Lanthanides Series*. Thomas D. O'Brien and editors. M. Cannon Sneed and Robert C. Brasted, Eds. Van Nostrand, New York, 1955. 193 pp. $5.

A History of the Classification of the Phylum Brachiopoda. Helen Marguerite Muir-Wood. British Museum (Natural History), London, 1955. 124 pp. £1.

The Expression of the Emotions in Man and Animals. Charles Darwin; with a preface by Margaret Mead. Philosophical Library, New York, 1955. 372 pp. $6.

Handbook for Teaching of Conservation and Resource-Use. Prepared by NABT National Conservation Committee, Richard L. Weaver, Project Leader, National Assoc. of Biology Teachers, Ann Arbor, Mich., in conjunction with American Nature Assoc., Washington, 1955 (Order from Project Leader, P.O. Box 2073, Ann Arbor Mich.). 499 pp. $4.

American Foundations and Their Fields. Wilmer Shields Rich. American Foundations Information Service, New York, ed. 7, 1955. 744 pp. $35.

The World We Live In. Lincoln Barnett and editorial staff of *Life*. Time Inc., New York, 1955. 304 pp. $13.50, regular edition; $15., deluxe boxed edition.

Wild America. The record of a 30,000-mile journey around the continent by a distinguished naturalist and his British colleague. Roger Tory Peterson and James Fisher. Houghton Mifflin, Boston, 1955. 434 pp. $5.

Science in Progress. Ser. 9. George A. Baitsell, Ed. Yale Univ. Press, New Haven, Conn., 1955. 343 pp. $6.50.

International Review of Cytology. G. H. Bourne and J. F. Danielli, Eds. Academic Press, New York, 1955. 419 pp. $9.

Protein Malnutrition. Proceedings of a conference in Jamaica (1953) sponsored jointly by The Food and Agriculture Organization of the United Nations (FAO), World Health Organization (WHO), and Josiah Macy, Jr. Foundation, New York. J. C. Waterlow, Ed. University Press, Cambridge, England, 1955. 277 pp.

Dried BCG Vaccine. Yoji Obayashi. World Health Organization, Geneva, 1955. 220 pp. $5.

College Algebra and Trigonometry. A basic integrated course. Frederic H. Miller. Wiley, New York; Chapman & Hall, London, ed. 2, 1955. 342 pp. $4.50.

Science, Religion & Reality. Joseph Needham, Ed., introductory essay by George Sarton. Braziller, New York, 1955. 355 pp. $3.95.

Addendum 1955 to the British Pharmacopoeia 1953. General Medical Council. Pharmaceutical Press, London, 1955. 93 pp. 21s.

The Prince of Botanists, Carl Linnaeus. Norah Gourlie. Witherby, London, 1953. 292 pp. 30s.

The Foreseeable Future. George Thomson. Cambridge Univ. Press, London, 1955. 166 pp. $2.50.

Infant Nutrition in the Subtropics and Tropics. D. B. Jelliffe. World Health Organization, Geneva, 1955. 237 pp. $5.

Income of the American People. Herman P. Miller. Wiley, New York; Chapman & Hall, London, 1955. 206 pp. $5.50.

The Bequest of the Greeks. Tobias Dantzig. Scribner's, New York, 1955. 191 pp. $3.95.

Understanding Surgery. Robert E. Rothenberg, Ed. Pocket Books, New York, 1955. 620 pp. $0.50.

Kinships of Animals and Man. A textbook of animal biology. Ann H. Morgan. McGraw-Hill, New York, 1955. 839 pp. $6.75.

Bibliographia Araneorum. vol. II, pt. 1. Pierre Bonnet. The Author, Université de Toulouse, 1955. 918 pp. $23.

Fishes of Japan. Illustrations and descriptions of the fishes of Japan. Yaichiro Okada. Maruzen, Tokyo, 1955. 463 pp. $10.

The Golden Book of Astronomy. A child's introduction to the wonders of space. Rose Wyler and John Polgreen. Simon and Schuster, New York, 1955. $3.95.

Biochemistry of the Developing Nervous System. Proceedings of the First International Neurochemical Symposium, held at Magdalen College, Oxford, 13–17 July 1954. Heinrich Waelsch, Ed. Academic Press, New York, 1955. 537 pp. $11.50.

Diesel Engine Principles and Practice. C. C. Pounder, Ed. Philosophical Library, New York, 1955. 848 pp. $17.50.

Histamine, Its Role in Anaphylaxis and Allergy. M. Rocha E. Silva. Thomas, Springfield, Ill.; Blackwell, Oxford, England, 1955. 248 pp. $7.50.

The Guilty Mind. Psychiatry and the law of homicide. John Biggs, Jr. Harcourt, Brace, New York, 1955. 230 pp. $4.50.

Plastics and Building. E. F. Mactaggart and H. H. Chambers. Philosophical Library, New York, 1955. 181 pp. $12.

Present-Day Psychology. An original survey of departments, branches, methods, and phases, including clinical and dynamic psychology. A. A. Roback, Ed. Philosophical Library, New York, 1955. 993 pp. $12.

Particle Size Determination. R. D. Cadle. Interscience, New York, 1955. 303 pp. $5.50.

Mutual Aid, a Factor of Evolution. Petr Kropotkin; foreword by Ashley Montagu; "The struggle for existence" by Thomas H. Huxley. Extending Horizons Books, Boston 8, 1955. 362 pp. cloth, $3; paper, $2.

The Natural History of North American Amphibians and Reptiles. James A. Oliver. Van Nostrand, New York, 1955. 359 pp. $6.95.

Prospecting for Atomic Minerals. How to look for and identify atomic ores, stake and protect a claim, evaluate and sell your minerals. Alvin W. Knoerr and George P. Lutjen. McGraw-Hill, New York, 1955. 211 pp. $3.95.

Atomic Energy Research at Harwell. K. E. B. Jay. Philosophical Library, New York, 1955. 144 pp. $4.75.

Experimental Pharmacodynamics. T. Koppanyi and A. G. Karczmar. Burgess, Minneapolis 15, 1955. 256 pp. $5.

Metallurgical Progress. vol. 2. Philosophical Library, New York; Cassier, London, 1955. 71 pp. $6.

Microscopy of Ceramics and Cements. Including glasses, slags, and foundry sands. Herbert Insley and Van Derck Frechette. Academic Press, New York, 1955. 286 pp. $7.50.